AEC Category: HEALTH AND SAFETY

CEX-58.8

CIVIL EFFECTS STUDY

COMPARATIVE NUCLEAR EFFECTS OF BIOMEDICAL INTEREST

Clayton S. White, I. Gerald Bowen,
Donald R. Richmond, and Robert L. Corsbie

Issuance Date: January 12, 1961

CIVIL EFFECTS TEST OPERATIONS
U.S. ATOMIC ENERGY COMMISSION

NOTICE

PRINTED IN USA
Price $1.00. Available from the Office of
Technical Services, Department of Commerce,
Washington 25, D. C.

USAEC Office of Technical Information Extension
Oak Ridge, Tennessee

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Washington, D. C.

September 1960

ABSTRACT

Selected physical and biological data bearing upon the environmental variations created by nuclear explosions are presented in simplified form. Emphasis is placed upon the "early" consequences of exposure to blast, thermal radiation, and ionizing radiation to elucidate the comparative ranges of the major effects as they vary with explosive yield and as they contribute to the total hazard to man. A section containing brief definitions of the terminology employed is followed by a section that utilizes text and tabular material to set forth events that follow nuclear explosions and the varied responses of exposed physical and biological materials. Finally, selected quantitative weapons-effects data in graphic and tabular form are presented over a wide range of explosive yields to show the relative distances from Ground Zero affected by significant levels of blast overpressures, thermal fluxes, and initial and residual penetrating ionizing radiations. However, only the "early" rather than the "late" effects of the latter are considered.

FOREWORD

Following submission of the initial draft of this brochure to the Atomic Energy Commission, the Civil Effects Test Operations of the Division of Biology and Medicine, arranged for a critical review by over 25 selected individuals, all knowledgeable in the field of weapons effects. Although most of the reviewers recognized the preliminary nature of the work, pointed out errors, and offered suggestions and constructive criticism, they expressed considerable interest in the presentation. This led to a collaborative effort between the Lovelace Foundation and the Civil Effects Test Operations to provide a corrected version of the first draft for reproduction, which essentially comprises the material that follows. Major revisions of the data are underway. Consequently, the present publication is regarded as an interim measure to serve only until an expanded text of the work can be made available. Since nuclear effects is a dynamic subject under continuous study, the reader can look to the future for the periodic appearance of quantitative data that will refine the basic understanding of nuclear phenomenology and the response of exposed physical and biological materials.

All the information contained herein is from unclassified sources, including scientific journals, text books, and Weapons Test Reports that document studies made during full-scale nuclear tests, many of which were carried out under the direction of the Civil Effects Test Operations. Since great effort was made to keep the Weapons Test Reports unclassified and to note bibliographic references, those interested can review the original publications. Too, much of the quantitative weapons-effects data utilized were drawn from the very informative and useful text *The Effects of Nuclear Weapons*, and the authors wish to acknowledge their indebtedness to this work which was so competently edited and prepared by Samuel Glasstone for the Department of Defense and published by the Atomic Energy Commission in June 1957. We are also grateful to personnel of the Sandia Corporation, Albuquerque, New Mexico, who not only contributed suggestions regarding the data included on residual radiation, but lent their analytical skill and arranged machine computations from which all the fallout charts were drawn.

Clayton S. White, M.D.

ACKNOWLEDGMENTS

The authors wish to express their deep appreciation to members of the Staff of the Sandia Corporation and the Lovelace Foundation who contributed computational, analytical, illustrative, editorial, and secretarial work that made this brochure possible.

Among the many individuals at Sandia Corporation with whom discussions were held, we wish particularly to express our thanks to Dr. W. W. Bledsoe, Mr. D. A. Young, Mr. M. Cowan, and Mr. B. N. Charles for their critical suggestions and analytical help along with timely machine computations.

Among the many persons at the Lovelace Foundation who contributed, we are especially grateful for additional machine computations to Mr. Ray W. Albright, who, along with Mr. Robert Perret, Mr. Malcolm A. Osoff, Mr. E. Royce Fletcher, and Mr. Jerome Kleinfeld, also lent analytical aid. Mr. John L. Howarth aided in preparing some of the text dealing with ionizing radiations.

The illustrative tasks, including graphs, the many fallout charts and photographic reproductions, were handled by Mr. Robert A. Smith, Mr. George A. Bevil, Mr. Edward M. Johnsen, and Mrs. Holly Ferguson.

Editorial and secretarial duties fell to Mrs. Isabell D. Benton, who, aided by Mrs. Barbara Kinsolving, typed the entire manuscript and spent many long hours checking the tables, text, and bibliographic references.

Lastly, the Lovelace Foundation wishes to acknowledge the support of the Division of Biology and Medicine of the U. S. Atomic Energy Commission and the Defense Atomic Support Agency who have jointly funded the work in Blast Biology over the past year. The coordinated understanding of both organizations has allowed perusal of work consonant with the interests of each agency including completion of this text, compilation of which was begun in previous years under contract with the Atomic Energy Commission.

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INTRODUCTION

The advent of nuclear weapons and their integration into programs vital to national defense emphasize the need for broad public knowledge of nuclear effects. Also, the increasing employment of nuclear materials in an expanding variety of peaceful applications serves notice that the public must learn to live in a nuclear age. Regardless of whether the future holds continued peace or the necessity of surviving a national emergency involving nuclear war, each individual citizen should share with the Government the responsibility of providing sensible levels of protection against nuclear effects.

The purpose of this publication is to provide citizens and Government alike with a single simplified source of information about nuclear weapons and related biological data which deals in a comparative way with effects due to blast and to thermal and ionizing radiations. Such data will help the average man assess for himself the risks he and his family face in the nuclear era and will provide background information for decisions and action regarding protective construction.

Accordingly, in the material that follows selected weapons-effects data have been assembled for quick reference to aid those interested in the physical and biological effects of nuclear weapons. The quantitative data are preceded by two sections chosen to facilitate orientation of the reader. The first section contains brief definitions of the terminology employed throughout the brochure. The second section deals grossly with the physical and biological consequences of the several environmental variations created by nuclear explosions. Such information will foster appreciation of the comparative ranges for the major effects as these vary with explosive yield and as these contribute to the total hazard to man.

It is well to point out here that the values for any given effect can vary considerably depending on many factors, not the least of which are weapon design and yield, location of burst, weather, terrain, and range from the detonation. Even though the numbers chosen are the outcome of experimental, theoretical, and full-scale studies in which many uncertainties were appreciated, they nevertheless represent best approximations and are reasonably valid for the purposes of orientation and planning. However, it should be pointed out that the figures for overpressure are thought to be reliable within ±20 per cent; those for thermal radiation within a factor of 2; and those for initial ionizing radiation within factors of 2 and 10 for the lower and higher explosive yields, respectively.

TERMINOLOGY AND DEFINITIONS

Bursts

SURFACE BURSTS: Bursts on or above the surface at heights that involve contact between the fireball and the surface of the earth.

TYPICAL AIR BURSTS: Air bursts in which there is no contact between the fireball and surface of earth and in which the heights are such as to produce maximal blast damage to an average city.

Explosive Yield

KILOTON (kt): A unit of explosive yield for a nuclear explosion; it is equivalent in energy to the energy released by the detonation of 1000 tons of TNT.

MEGATON (Mt): A unit of explosive yield equivalent in energy to 1000 kt, or 1,000,000 tons, of TNT.

Fission Yield

FISSION YIELD: That portion of the total explosive yield of a nuclear explosion attributable to nuclear fission. The units are *kilotons* and *megatons*. Megatons of *fission* yield are to be distinguished from megatons of *total* yield.

Blast Pressures

OVERPRESSURE: The transient pressure variation above the ambient produced by an explosion; it travels radially from the source of the detonation.

LOCAL-STATIC OR INCIDENT PRESSURE: The overpressure measured side-on to the advancing front of an explosive-produced overpressure.

REFLECTED PRESSURE: The instantaneous pressure that occurs when a pressure front strikes a surface.

DYNAMIC PRESSURE (Q): The difference between the pressures measured head-on and side-on to an advancing pressure pulse associated with an explosion. Thus Q, or dynamic pressure, is a measure of the force exerted by the blast winds. Hurricane wind velocities by definition are 75 mph or greater.

POUNDS PER SQUARE INCH (psi): A unit used to express the force exerted by blast-produced pressures.

MAXIMAL OVERPRESSURE ($P_{max.}$): The maximal overpressure existing at any location due to an explosion. This may refer to incident or reflected pressures.

PRIMARY, SECONDARY, AND TERTIARY BLAST EFFECTS: Primary, secondary, and tertiary blast effects are biologically those due, respectively, to (1) pressure variations per se, (2) the impact of penetrating or nonpenetrating missiles energized by the blast, and (3) the physical displacement of a target by blast winds (may be damaging during the accelerative or decelerative phase of the experience).

GEOMETRIC MEAN: The antilog of the mean of the logarithms of a series of data. The log transformation normalizes some skewed distributions, and, when such is the case, the geometric mean is numerically equal to the *median* rather than the *mean* of the data.

Thermal Radiation

THERMAL RADIATION: That portion of the energy of an explosion released as heat-producing rays, whether as visible light or as invisible radiation in the ultraviolet and infrared portions of the energy spectrum.

CALORIES PER SQUARE CENTIMETER (cal/cm^2): A unit conventionally used to denote the quantity of thermal energy reaching any given target.

IGNITION ENERGY: That thermal dose, expressed in calories per square centimeter, required to ignite specified material.

SKIN BURNS

First-degree Burns: Flash or flame burns producing only redness of the skin and roughly similar to a moderate sunburn.

Second-degree Burns: Burns that produce superficial or deep blisters of the skin. In case a significant area of the body is involved, these burns usually require expert medical care.

Third-degree Burns: Burns of such severity as to completely destroy the full thickness of the skin, healing taking place by the process of scar formation. Even relatively small areas, particularly involving the face, hands, or flexion surfaces of the body, require prolonged medical attention including skin grafting.

FLASH BLINDNESS: A temporary loss of vision due to exposure to intense light.

RETINAL BURNS: Destruction of portions of the inner wall of the eye containing the nerves concerned with sight as a result of the focusing of an image of an intense light source on the retina.

Ionizing Radiation

INITIAL (PROMPT) RADIATION: The initial nuclear radiation, mostly neutrons and gamma rays, is that emitted from the ball of fire and the cloud column within 1 min after a nuclear detonation.

RESIDUAL RADIATION: The residual nuclear radiation, mostly gamma rays and beta particles, is that emitted after 1 min following a nuclear explosion; it consists of emanations from fission products or from induced activity in air, soil, or other material.

FALLOUT RADIATION: Fallout radiation is that portion of the residual radiation which reaches the surface of the earth from the radioactive cloud or cloud stem.

ROENTGEN (r)*: The unit of exposure dose of X or gamma radiation.

ACCUMULATED EXPOSURE DOSE: The total dose of radiation to which an individual has been exposed from single, multiple, or continuous exposure to a source of ionizing radiation.

INFINITY DOSE (r_∞): The accumulated exposure dose of radiation from continuous exposure to a certain quantity of radioactive material over infinite time.

ISODOSE LINE: A line joining points or locations where the exposure doses are equal.

ROENTGEN PER HOUR (r/hr)*: The unit of exposure dose rate expressed in exposure dose per unit time.

ISODOSE RATE LINE: A line joining points or locations where the exposure-dose rates are equal.

HODOGRAPH: A mathematical term referring to the path or graph of a variable vector, used here to illustrate the paths of fallout in terms of a radioactive particle of specified size as these vary with the winds aloft and weapon yield.

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*Taken from National Bureau of Standards Handbook 62, 1956,[48] to which the reader is referred for more precise definitions and explanations. Also, see *Radiological Health Handbook*, U. S. Department of Health, Education and Welfare, 1957.[28]

RELATIVE BIOLOGICAL EFFECTIVENESS (RBE)*†: An expression used to compare the biological effectiveness of different kinds of ionizing radiation.

RAD: A unit of absorbed dose (1 rad = 100 ergs/g).

ROENTGEN EQUIVALENT MAN (rem)*†: The unit of the RBE dose; it is equal to the radiation dose in rads multiplied by an appropriate RBE.† [Note: Although there are very real distinctions between exposure dose (r), absorbed dose (rads), and biologically effective dose (rem), the roentgen and rad units are, numerically speaking, not too different. Neither does the rem value for X or gamma radiation numerically vary much from those expressed in roentgen or rad units since the RBE by definition is approximately 1. Once the absorbed dose (in rads) for neutrons is converted to rem, using an appropriate RBE, the numerical value represents a gamma equivalent of the neutron dose. Consequently, for practical purposes, the reader may regard the rem values noted in future sections of the brochure as roughly equivalent numerically to the exposure dose in roentgens. Although, strictly speaking, this is technically incorrect, the errors involved in such an approximation are generally much smaller than the other sources of uncertainty and seem acceptable on this basis.]

EFFECTIVE BIOLOGICAL DOSE (EBD): This is the accumulated exposure dose of radiation corrected for biologic recovery and repair that has occurred at a particular and specified time after exposure. Some consider radiation injury as approximately 90 and 10 per cent reparable and irreparable, respectively, with the former being accomplished in about three months, but nearly 50 per cent complete in one month.‡ Recognizing the EBD will allow a more refined prediction of medical and biological effects of radiation and the recovery therefrom.

EFFECTIVE ACCUMULATED DOSE (EAD): The accumulated exposure dose of radiation corrected by a factor proportional to the EBD as appropriate to the time in question.

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*Taken from *U. S. Bureau of Standards Handbook 62,* 1956,[48] to which the reader is referred for more precise definitions and explanations. Also see *Radiological Health Handbook,* U. S. Department of Health, Education and Welfare, 1957.[28]

†For the data given later covering initial radiations, the rem values were computed using an RBE for bomb neutrons of 1.7, as was done in *The Effects of Nuclear Weapons.*[24]

‡See National Council on Radiation Protection Subcommittee 14 Handbook, *Exposure to Radiation in an Emergency.*[49]

ORIENTATION

Physical Parameters

BLAST EFFECTS

Pressure (Incident, Reflected, Dynamic) and Wind Velocity: Since both overpressure and wind are responsible for damage by blast, it is helpful to note the approximate relationships set forth in Table 1. It is important to appreciate the relationship between the incident and reflected pressure and to know that field experience has shown considerable variation in the dynamic pressures related with a given incident overpressure. For example, at an incident overpressure of 6 to 7 psi, a dynamic pressure of about 15 psi was measured in the 1957 Nevada Test Series.*

Pressure and Structures: Table 2 details a few of the approximate relationships between overpressure produced by nuclear blast and the resultant damage to structures.

Pressure and Missiles†: The velocities and masses of glass and stone missiles energized by blast winds in full-scale nuclear tests at the Nevada Test Site are set forth in Table 3.

*Pressure and Displacement of Man**: The measured maximum velocity and displacements of 165-lb anthropometric dummies (simulating man) exposed to nuclear blasts at the Nevada Test Site are shown in Table 4.

THERMAL EFFECTS

Ball of Fire: Most but not all structures located within the luminous fireball of a nuclear detonation are vaporized or otherwise destroyed. However, heavy-concrete aboveground installations have survived at the Nevada Test Site even when situated inside the fireball radius. This is mentioned because exposure inside the fireball need not be invariably fatal, providing sufficient insulation from the high temperatures and shielding from high fluxes of ionizing radiation are arranged, along with appropriate protection from blast overpressures and winds, e.g., closed deep underground structures and locations.

Emission: Thermal energy from an explosion in air is emitted rapidly from the fireball in two pulses: a short pulse measured in fractions of a second and encompassing only about 1 per cent of the total thermal yield and a long pulse of many seconds duration which carries 99 per cent of the total thermal energy. The blink reflex of the eye, therefore, can give effective protection as can evasive measures taken promptly. For bursts in the outer fringes of the earth's atmosphere and in space, thermal emission occurs very quickly as a single pulse and high energies are transmitted in fractions of a second thus precluding the effectiveness of the blink reflex or evasive measures should one be looking toward the fireball.

Attenuation: Thermal energy travels radially from the fireball with the speed of light, and, as it passes through air, it undergoes attenuation with distance because (1) it is spread over larger areas, (2) absorption by the air occurs (particularly for the shorter wave

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*Report WT-1469.[40]

†Reports WT-1168[5] and AECU-3350.[6]

Table 1—CALCULATED WIND-VELOCITY RELATIONS WITH PRESSURE PARAMETERS (SEA LEVEL)*

Maximum pressure, psi Incident	Reflected	Dynamic†	Wind velocity, mph
1	2	0.02	40
2	4	0.1	70
5	11	0.6	160
10	25	2	290
20	60	8	500
30	100	16	670
50	200	40	940
100	500	125	1400

*Data computed from *The Effects of Nuclear Weapons.*[24]

†A hurricane wind of 120 mph exerts a dynamic pressure of about 0.25 psi.

Table 2—RELATION BETWEEN OVERPRESSURE AND PHYSICAL DAMAGE*

Type of structural material	Over-pressure, psi	Physical effects
Glass:		
Window	0.1	Damage
Plate	0.02	Damage to large glazed areas
Houses:		
Wooden	1–2	50 per cent damaged
	4–5	Destroyed
Brick	5	Destroyed
Apartments, brick	4–5	Moderate damage
	5–7	Severe damage
Reinforced concrete	4–6	Moderage damage
Frame buildings	6–8	Severe damage
Wall-bearing massive buildings	6–8	Moderate damage
	8–10	Severe damage
Motor vehicles	2–3	Light damage
	10–15	Severe damage
Parked aircraft	1–3	Minor to major repair required
	4–6	Unusable to destroyed

*Selected from *The Effects of Nuclear Weapons,*[24] SCTM 195-58(51).[41]

Table 3—RELATION BETWEEN OVERPRESSURE AND MISSILE PARAMETERS*

Max. pressure, psi	Type of missile	Velocity, ft/sec Geometric mean	Velocity, ft/sec Range	Mass, g Geometric mean	Mass, g Range	Max. missile density, missiles/sq ft
1.9	Window glass	108	50–178	1.45	0.03–10	0.4
3.8	Window glass	168	60–310	0.58	0.01–10	159
5.0	Window glass	170	50–400	0.13	0.002–140	388
8.5	Natural stones	275	167–413	0.23	0.038–22.2	35
15.0	Natural stones	692	379–1100	0.50	0.043–8.82	4.7
17.3	Natural stones	432	300–843	0.21	0.010–13.4	99.1
17.3	Irregular steel objects	240	195–301	34.5	9.0–86.0	3.6

*Reports WT-1168,[5] AECU-3350,[6] and TID-5564.[44]

Table 4—BLAST DISPLACEMENT OF 165-LB ANTHROPOMETRIC DUMMIES*

Max. pressure, psi	Max. Q, psi	Initial dummy position	Max. horizontal velocity, ft/sec	Time to max. velocity, sec	Displacement, ft
5.3	0.7	Standing	21.0	0.5	21.9 downwind
		Prone	0		None
6.6	15.8	Standing	Not known	Not known	256 downwind, 44 to right
		Prone	Not known	Not known	124 downwind, 20 to right

*Report WT-1469.[40]

lengths), and (3) radiation is scattered (all wave lengths) by air molecules and other gaseous and particulate components of the atmosphere (clouds, fog, smoke).

Shielding: Mostly, thermal energy, like light, travels in straight lines, and "shadowing" by terrain, buildings, window shades, and even clothing gives some shielding. Highly reflecting surfaces interposed between the target and the source, such as aluminum foil, are surprisingly effective shields.

Augmentation: Bursts below white-cloud cover, because energy is scattered back toward the earth, may show augmented thermal effects. Similarly, exposure in front of a reflecting surface will increase the thermal energy received by a target.

Ignition Energies: Thermal energies required to ignite houses and a few common materials are listed in Table 5. The reader will note that more energy is required from larger than from smaller weapons to ignite material. One reason for this is that energy is delivered to the target faster with the smaller yield than it is with the larger explosive yields.

Ignition Points in American Cities: Exterior ignition points per acre in and near American cities are given in Table 6.

Fire Storm: The reader is referred to *The Effects of Nuclear Weapons*[24] for information regarding fire storm.

IONIZING-RADIATION EFFECTS

Simultaneously with and following a nuclear reaction or explosion, ionizing radiations, invisible but harmful to man, are emitted. These consist of neutrons, gamma rays, and beta and alpha particles. Most neutrons and some gamma rays are produced when either fission or fission and fusion occur. The remainder of the gamma rays and the beta particles arise from the decay of fission products. Alpha particles are formed in hydrogen fusion reactions and are emitted by uranium and plutonium that escape fission. Alpha and beta particles have very short ranges; consequently, the discussion will be limited to neutrons and gamma rays, which comprise the penetrating nuclear radiations. Because there are important variations in the times of delivery of radiation energy following a nuclear explosion, the most significant radiation problems will be discussed under two headings: initial radiation (occurring during the first minute) and residual radiation (occurring after the first minute following a nuclear burst).

INITIAL RADIATIONS

Neutrons: Within one millionth of a second after a nuclear detonation, 99 per cent of the prompt neutrons of various energies are produced; the remaining 1 per cent, the delayed neutrons, are emitted well within 1 min. In fact, although scattering occurs in the immediate vicinity of the explosion and the neutrons follow lengthy zig-zag pathways, nearly all the prompt neutrons escape the exploding source within 1/100 sec. During the next second these neutrons have travelled at somewhat less than the speed of light to those ranges within which their effects represent a hazard to man. There is, therefore, hardly time for any evasive action.

Gamma Rays: Depending much upon yield and range, evasive action may be effective against exposure to a significant portion of the gamma radiation, as Table 7 illustrates. This follows because the prompt gamma radiations—associated with fission, neutron reactions, and excitation of bomb materials, and all emitted within 1 sec—are followed by the delayed gamma radiations arising from the rising fireball and cloud, which contain radioactive fission products and debris. It is clear from Table 7 that at a range of 1.5 miles from a 5-Mt detonation, 85 per cent of the total gamma dose is delivered between the first and the tenth second; whereas the figure is 30 per cent for the 20 kt yield at a range of 0.5 mile. Thus, moving quickly behind some substantial object immediately after a flash might mean the difference between a fatal and a nonfatal exposure to initial nuclear radiations.

Emission: Somewhat analogous to thermal radiation, the initial ionizing radiation is emitted after a nuclear detonation in air over two time periods: an early period of about 1 sec, during which all the neutrons and a relatively small portion of the gamma (prompt) radiation emanate from the vicinity of the reacting fissionable material and fireball, and subsequently a delayed period enduring up to 1 min after the explosion, during which the

Table 5—THERMAL ENERGIES REQUIRED TO IGNITE HOUSES AND MATERIAL*

Material	Ignition energy, cal/cm^2 20 kt	10 Mt
Wooden houses:		
Weathered	12	
Freshly painted white	25	
Newspaper	3	6
Wool flannel, black	8	16
Cotton shirting, tan	7	13
Cotton auto seat covers, green, brown, white	9	16
Rayon taffeta, wine	2	3
Fine kindling fuels	5	7
Fine grass	5	10

*Selected from *The Effects of Nuclear Weapons.*[24]

Table 6—EXTERIOR IGNITION POINTS IN AND NEAR SURVEYED AMERICAN CITIES*

Classification of area	Approx. No. ignition points per acre	Classification of area	Approx. No. ignition points per acre
Wholesale distribution	27	Small manufacturing	7
Slum residential	20	Downtown retail	4
Neighborhood retail	11	Good residential	3
Poor residential	9	Large manufacturing	3

*Selected from *The Effects of Nuclear Weapons.*[24]

Table 7—PERCENTAGE OF TOTAL INITIAL GAMMA-RADIATION DOSE RECEIVED AT RANGES OF 0.5 AND 1.5 MILES FROM 20-KT AND 5-MT NUCLEAR DETONATIONS, RESPECTIVELY, AS A FUNCTION OF TIME*

Explosive yield	Range, miles	Percentage of initial gamma-radiation dose delivered at indicated times 1 sec	2 sec	4 sec	7 sec	10 sec	15 sec	20 sec
20 kt	0.5	67	78	88	95	97	100	100
5 Mt	1.5	5	17	43	76	90	98	100

*Selected from *The Effects of Nuclear Weapons.*[24]

remainder of the initial gamma radiation is given off by the rising fireball and radioactive cloud.

Attenuation: The initial ionizing radiation moves away from the source at speeds equal to, and somewhat less than, the speed of light for the gamma rays and neutrons, respectively. This radiation undergoes attenuation with distance for a number of reasons, the most important being (1) the greater area over which the radiation is spread with increasing range; (2) absorption by air, which is generally less effective for high than for low energy radiation and more effective for neutrons than for gamma rays; and (3) scatter by air molecules and other material contained in the atmosphere. Appreciation of the comparative attenuation of the initial neutrons and gamma rays by air is given by a quantity known as the "relaxation length" of the radiation, which is that distance required to reduce the radiation dose by a factor of e (= 2.7183), the base of the natural logarithms. The relaxation length is dependent upon the air density (and hence the mass of material traversed by the radiation) and the energy and kind of radiation involved. At sea level and for initial bomb radiation, the relaxation length is 338 yards (1014 ft) for gamma and 242 yards (726 ft) for neutron radiations. A consequence of this fact is that neutron dose decreases more rapidly with increasing range than does the gamma dose, and at the greater ranges only gamma rays contribute significantly to the hazard from initial radiation.

Augmentation: Three factors contribute to increase the radiation exposure of a given target during the first minute after a nuclear explosion above the dosage due to radiations coming from the fissioning material, the fireball, and the nuclear cloud. These are: (1) scatter of radiation from materials, including air, close to the target; (2) activation or excitation of materials in the vicinity of the target by neutrons, particularly the nitrogen contained in the atmosphere and elements in soil and structures; and (3) a decrease in air density associated with the negative phase of the blast pressures, which results in less attenuation of the gamma radiation by air and which is particularly effective in increasing the range of gamma rays for the larger yield explosions; i.e., the relaxation length applicable to gamma rays increases with lower air density and hence attenuation by the atmosphere decreases.

Neutron/Gamma Ratios: The relative contribution of neutrons and gamma rays to the initial radiation is sensitive to the design and yield of the nuclear device, to range, and to factors that contribute to attenuation and augmentation of the radiation. Some appreciation of the interplay of all these intangibles as they control the percentage of neutron and gamma dose is shown in Table 8, which gives the approximate neutron and gamma portions of the hazard as these vary with explosive yield. The ranges used for each yield are those in which the radiation would be 600 and 200 rem. The yields for which the gamma and neutrons would each contribute 50 per cent of the total biological dose of 200 and 600 rem would be near 15 and 30 kt, respectively. Table 8 shows that for yields less than these the neutrons contribute more of the dose than do the gamma rays. The reverse is true for the higher yields. Likewise, for higher doses than those shown, and therefore at lesser ranges, the neutron contribution would be greater than listed in Table 8. There are, of course, uncertainties with regard to Tables 7 and 8 which concern fission-fusion ratios for a given explosion because as the fission portion of the total yield decreases, so does the delayed gamma-ray contribution to the initial radiation that arises mostly from fission products in the fireball, stem, and cloud. To the contrary, the neutron and prompt-gamma contributions to the initial radiation will increase.

Shielding: Shielding from penetrating initial radiation arising from a nuclear explosion involves many complexities, not the least of which concern differences between neutrons and gamma rays, the wide energy range of each, and variations associated with shield thickness and materials. However, certain practical generalizations are useful. For example, the reduction of gamma radiation is related to the density of material through which the radiation passes, as illustrated in Table 9, which notes the thickness of materials of specified density that attenuate the radiation by a factor of 2. The reader will note that the product of the density of the shield and the half-value layer is about equal to 800. Thus, if the density (x) in pounds per cubic foot of a potential shield is known,

Table 8—APPROXIMATE RELATIVE CONTRIBUTIONS OF NEUTRONS AND GAMMA RAYS TO THE INITIAL RADIATION EXPRESSED AS PERCENTAGE OF TOTAL BIOLOGICAL DOSE OF 600 AND 200 REM FOR DIFFERENT EXPLOSIVE YIELDS*

Total biologic dose, rem	Kind of radiation	Approximate percentage contributions of gamma rays and neutrons to the initial radiation for indicated yields						
		1 kt	20 kt	100 kt	500 kt	1 Mt	5 Mt	20 Mt
200	Neutrons	70	48	30	5	2	~0	~0
	Gamma	30	52	70	95	98	~100	~100
600	Neutrons	62	57	38	7	3	1	~0
	Gamma	38	43	62	93	97	99	~100

NOTE: The levels of exposure chosen "fixed" the range for each yield; e.g., the ranges were those which resulted in a total biologic dose of 200 and 600 rem.

*Selected from *The Effects of Nuclear Weapons.*[24]

Table 9—APPROXIMATE SHIELDING CHARACTERISTICS OF MATERIAL AGAINST INITIAL GAMMA RADIATION SHOWING THE RELATION BETWEEN SHIELD DENSITY AND THE THICKNESS THAT WILL REDUCE THE RADIATION BY ONE-HALF*

Materials	Density, lb/cu ft	Half-value thickness, in.	Product
Lead	707	0.6	
Steel	490	1.5	735
Concrete	144	6.0	864
Earth	100	7.5	750
Water	62.4	13.0	811
Wood	34	23.0	782

NOTE: Assumes 4.0 Mev is an adequate representation of the energy of initial gamma radiation and incorporates build-up factors correcting for thick shields and broad radiation beams (see pages 353 to 360 and 374 to 380, *The Effects of Nuclear Weapons*).

*From *The Effects of Nuclear Weapons.*[24]

its half-value thickness can be estimated by dividing 800 by this number; i.e., 800/x = half layer thickness in inches. Also, through the use of numbers close to those in Table 9, it is possible to compute the thickness of materials that will attenuate initial gamma radiation by different amounts. As a convenience, Table 10 shows such data for quick reference.

Also of interest are recent studies of Ritchie and Hurst[33] noting the shielding from initial gamma radiation provided by light-frame houses. Such data incorporate the angular distribution of radiation which occurs under full-scale nuclear conditions. Figure 1 shows gamma attenuation as a function of penetration distance for two identical houses measured in opposite orientations with dosimeters placed 42 and 84 in. above the floor. Similar data from the same authors[33] are presented in Fig. 2, which gives the attenuation values for initial neutron radiation as a function of house-penetration distance. Although the shielding afforded by houses may reduce the neutron dose by as much as a factor of 2, the attenuation is appreciably less than this for gamma rays. In any case, the shielding potential of houses against bomb radiations is small, but, at certain combinations of range and yield, it could be critical in reducing radiation fatalities.

In general, shielding against neutrons is much more complex than shielding against initial gamma rays, and there is no straightforward correlation between attenuation and the density of material as applies with good approximation to gamma radiation. An adequate shield must not only attenuate fast neutrons, but must also capture the slowed-down neutrons and absorb any radiation that accompanies the capturing process. Boron or boron-containing minerals, such as colemanite, are useful as absorbers of thermal neutrons, the process being accompanied by the emission of low-energy gamma rays (0.48 Mev). Since the latter are not difficult to attenuate, the inclusion of boron has advantages in shielding against neutrons and will significantly reduce the induced radiation on surfaces covered with colemanite or in boron-containing materials such as concrete.[24] Table 11 shows the thickness of different types of concrete which will reduce neutron radiation by a factor of 2, i.e., the half-value thickness, and by factors varying from 10 to 100,000.

RESIDUAL RADIATION

The residual ionizing radiation, that occurring subsequent to 1 min following a nuclear explosion, arises mainly from bomb residues including fission products, activated bomb and other debris, and unfissioned uranium or plutonium. Although beta and alpha particles form a significant portion of the residual radiation, the present discussion will be limited to gamma rays, the penetrating portion of the residual radiation.

Emission: Penetrating gamma radiation from radioactive material in the rising fireball, stem, and cloud is emitted "continuously" as it is when there is induced radiation in soil, water, structures, and other materials. In case of an explosion in air wherein the fireball makes no contact with the earth, the hazardous materials, as small particulates and gases, are carried to altitude and subsequently either fall back to the earth as dictated by gravity and the winds aloft in time periods like minutes, hours, and days (early fallout) or are carried to the higher reaches of the atmosphere to undergo non-uniform world-wide distribution and eventual deposit on the earth's surface in periods like weeks, months, and many years (delayed fallout). The larger the yield, the higher the fireball, stem, and cloud are carried and the more likely is fallout to be a delayed as well as an early problem.

Surface or near-surface explosions carry tons of material, some of it radioactive by neutron activation, up into the stem and cloud where it is mixed and condensed with fission products and bomb debris. This mixture also either falls back to earth in the shorter time periods or reaches altitudes wherein world-wide distribution occurs, depending much upon explosive yield. However, the surface burst tends to maximize the early fallout problem with which the subsequent text will deal.

The amount of radioactive debris formed in a nuclear explosion is mostly a function of fission yield rather than total explosive yield, although neutrons from fusion reactions add to the induced radioactivity. Too, the induced components of the penetrating residual radiation are sensitive to the character of the materials exposed in the vicinity

Table 10—APPROXIMATE ATTENUATION FACTORS FOR INITIAL GAMMA RADIATION AS A FUNCTION OF SHIELD THICKNESS FOR INDICATED MATERIALS*

	Shield thickness for the indicated materials, in.					
Attenuation factor	Lead (710 lb/cu ft)	Iron and steel (490 lb/cu ft)	Concrete (144 lb/cu ft)	Earth (100 lb/cu ft)	Water (62.4 lb/cu ft)	Wood (Fir) (3.4 lb/cu ft)
2	0.6	1.3	5.5	8	12	22
4	1.3	2.6	11	16	25	44
10	2.2	4.3	18	26	42	73
50	3.6	7.3	30	43	70	123
100	4.3	8.5	35	51	83	145
1,000	6.3	12	52	73	124	216
10,000	8.2	16	68	93	168	291
100,000	9.9	19	84	112	203	396

*From *The Effects of Nuclear Weapons.*[24]

Table 11—APPROXIMATE SHIELD THICKNESS REQUIRED TO ATTENUATE NEUTRON RADIATION BY THE INDICATED FACTORS

Type of concrete or aggregate	Concrete density, lb/cu ft	Concrete thickness to reduce neutron radiation by indicated factors, in.					
		2	10	100	1,000	10,000	100,000
Ordinary*	144	3	10	20	30	40	50
Ordinary†	143.3	2.2	7.3	15	22	29	37
Ordinary	146.7	4.2‡	14	28	52	64	70
Ordinary§	149.8	3.5	12	23	35	47	58
Ordinary + 1.25% Pyrex	149.2	2.9‡	9.6	19	29	38	48
Magnetite	236.0	3.3‡	11	22	33	44	55
Limonite	164.2	1.9‡	6.3	13	19	25	32
Limonite + scrap iron	275.5	2.2‡	7.4	15	22	30	37
Limonite + scrap iron + 0.7% Pyrex	224.7	2.0‡	6.6	13	20	26	59

*Data from Glasstone[24] for bomb neutrons.

†Data from Blizard and Miller[4] for thermal neutrons.

‡Half-value thickness (attenuation by a factor of 2) from Callan[10] for thermal neutrons. Other data calculated.

§Data from Price et al.[29] for fast neutrons.

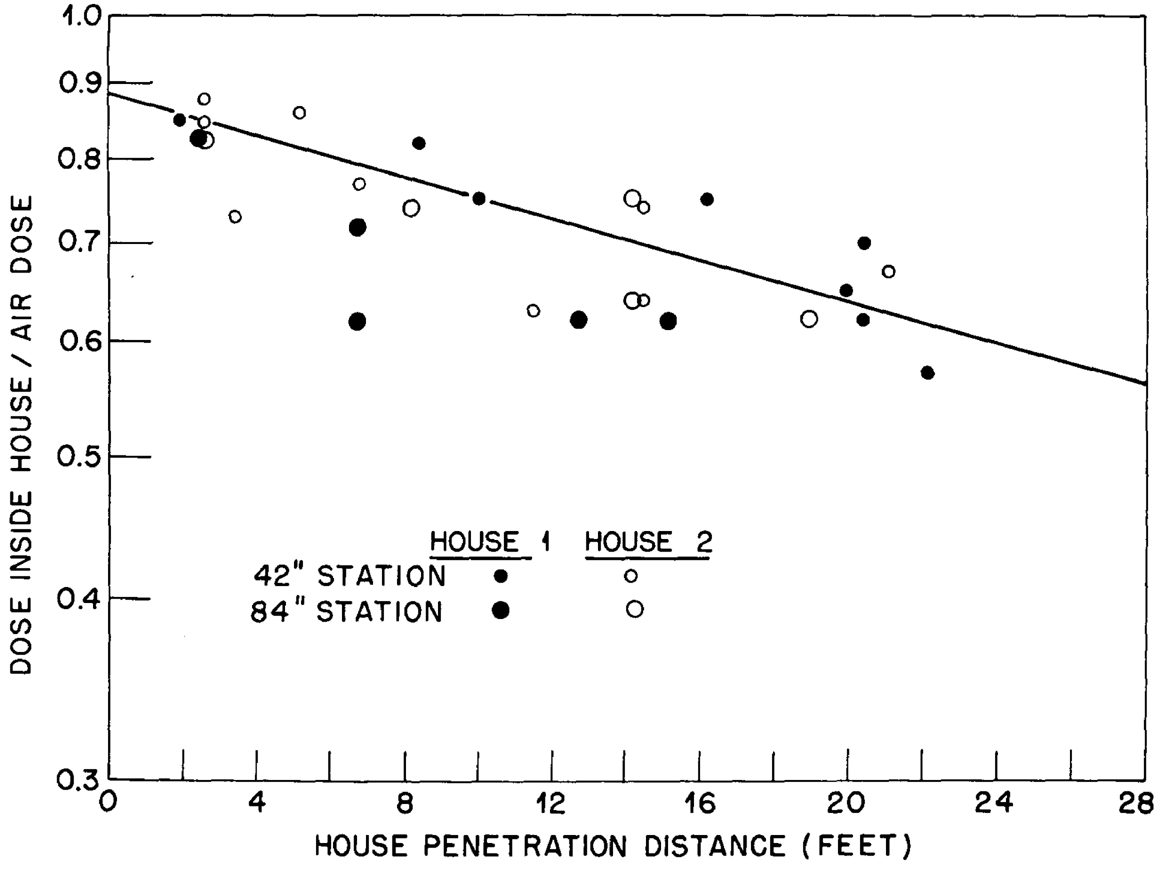

Fig. 1—Attenuation of gamma radiation by typical single-story Japanese houses. (Data from Ritchie and Hurst.[33])

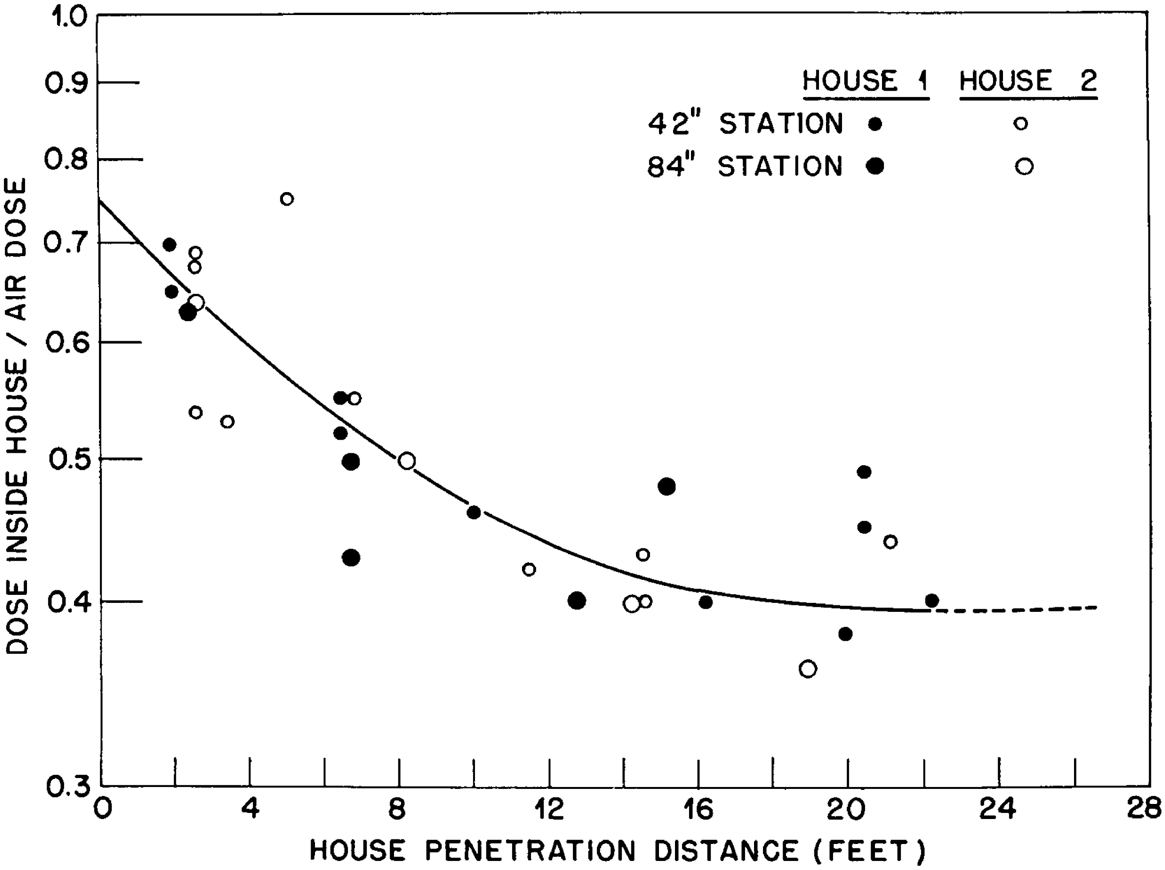

Fig. 2 — Attenuation of fast neutrons by typical single-story Japanese houses. (Data from Ritchie and Hurst.[33])

of an explosion; e.g., some elements when made radioactive remain so for long periods of time, others only for short periods.

Decay: Fortunately, the intensity of the residual nuclear radiation decreases with time after an explosion, as shown by Table 12, which indicates that only about 2 and 0.2 per cent of the gamma radiation at 1 hr remain 1 day and 1 week, respectively, after the detonation. For general applications, the seven-tenths rule is useful in making rapid approximations of the decay with time of a known level of residual gamma radiation measured at a particular time. The rule states that as time increases by a factor of 7, the gamma-ray intensity decreases by a factor of 10. The application of this simple relationship is illustrated in Table 13.

Attenuation: Besides radiation decay there are other factors that tend to decrease the residual radiation reaching, or existing at, a given surface area. The first is the height of the cloud and stem, which is mostly yield dependent. The second is the particle size of the fallout debris. The third is the winds aloft, and the fourth is weathering and leaching of the soil by wind and rain, which tends to spread the radioactive material further or to carry it into subsurface layers of the soil. The first three factors bear upon the time of fallout arrival and the total surface area over which it is spread. Both a delay in arrival and an increase in area decrease the level of contamination. Table 14 illustrates these facts by giving the particle-size distribution of material in an atomic cloud at an altitude of 80,000 ft; their time of fall to the earth's surface; the distance travelled by particulates of selected size groupings during this period, assuming a 15-mph wind at all altitudes; and the average radiation of selected size groupings expressed as a percentage of the initial activity in the cloud right after the burst and when the particles would arrive at the surface of the earth, allowance being made for decay during transport through the atmosphere. Consider the radiation contained in the 150 to 75μ group of particles to average about 18 per cent of the total activity just after the burst. Subsequently, decay occurs during transport to and from an altitude of 80,000 ft. In coming down, the particles would be transported 59 to 240 miles for the larger and smaller particles, respectively, taking from about 4 to 16 hr. The average activity in this range of particle sizes would have decayed to near 0.015 per cent of the initial dose rate by the time the particles reached the surface of the earth.

Once the penetrating radiation is on the ground, a "flat" radioactive surface is formed, and attenuation with distance above the surface is not straightforward, first, because radiation is received from below and laterally at all angles and, second, because the radiation is scattered from the air molecules, the so-called "sky-shine." Practically, doses received at increasing distances above the surface do not fall off very rapidly, as Table 15 shows; e.g., at 20, 150, and 500 ft the radiation has decreased by factors of about 2, 3, and 10, respectively.

Shielding: The above information bears somewhat upon shielding provided by above-ground structures against radiation from a uniformly contaminated plane. The problem is complicated by (1) the redistribution of source material due to the presence of the structure—material on the roof rather than the ground—and (2) the attenuation of radiation due to structural materials and the contents of the building. However, Table 16 sets forth approximate protection factors that can be expected from shielding by light-frame structures against simulated penetrating fallout radiation. The table also notes that a shelter covered by 3 ft of earth will give a shielding factor of 1000 or more against radiation from fallout. Table 17 presents shielding data for various materials showing the attenuation factors for penetrating residual radiations. Since the latter have energies averaging less than those of the initial gamma radiation, shielding is less difficult, and the reader should not confuse the attenuation factors for initial gamma radiation given in Table 10 with those for fallout gamma rays set forth in Table 17.

Biological Parameters

BLAST EFFECTS

Primary (Pressure) Effects: It is now known that the tolerance of mammals (if the eardrums and sinuses are ignored) to variations in environmental pressure depends a great

Table 12—DECAY OF RESIDUAL GAMMA RADIATION FROM AN EXPLOSION HAVING A 1-MT FISSION YIELD*

Time after explosion	Activity, megacuries	Activity, %
1 hour	300,000	100
1 day	6,600	2.2
1 week	640	0.213
1 month	110	0.037
1 year	5.5	0.0018

*Data from *The Effects of Nuclear Weapons.*[24]

Table 13—SEVEN-TENTHS RULE FOR APPROXIMATING DECAY OF RESIDUAL GAMMA RADIATION*

Time after burst				
Hr	days	Time factor	Dose rate, r/hr	Dose-rate factor
1	0.04	1	1000	1
7	0.29	7	100	1/10
49	2.04	7^2	10	1/100
343	14.3	7^3	1	1/1000
2401	100	7^4	0.1	1/10,000

NOTE: These data are based upon the formula generally used; i.e., $R_t = R_1 t^{-1.2}$, where R_1 is the dose rate at some instant and R_t is a later dose rate after an interval of time, t, has passed. This relationship is not strictly applicable to very early or very late times after a burst, nor does it apply to a given location on the earth's surface until fallout is complete.

*Data from *The Effects of Nuclear Weapons.*[24]

Table 14—APPROXIMATE TIMES OF FALL OF VARIOUS SIZED RADIOACTIVE PARTICULATES FROM 80,000 FT AND DISTANCE TRAVELED IN A 15-MILE WIND (AT ALL ALTITUDES) AS RELATED TO PROPORTION OF INITIAL GAMMA ACTIVITY AT ALTITUDE AND AT SURFACE CORRECTED FOR DECAY DURING TRANSPORT*

Particle diameter, μ	Time of fall, hr	Distance traveled in 15-mph wind, miles	Percentage of initial activity	Percentage of initial activity deposited
>340	Up to 0.75	Up to 11	3.8	0.0394
340–250	0.75–1.4	11–21	12.6	0.0964
250–150	1.4–3.9	21–59	14.5	0.0460
150–75	3.9–16	59–240	18.1	0.0154
75–33	16–80	240–1200		
33–16	80–340	1,200–5,100		
16–8	340–1400	5,100–21,000		
8–5	1400–3400	21,000–51,000		

*Data from *The Effects of Nuclear Weapons.*[24]

Table 15—APPROXIMATE ATTENUATION OF RESIDUAL GAMMA (0.7 MEV) RADIATION WITH DISTANCE ABOVE EARTH'S SURFACE*

Distance above ground, ft	Attenuation factor	Distance above ground, ft	Attenuation factor
20	2	500	10
150	3	1000	30
300	5	2000	300

NOTE: The attenuation factors apply to 0.7-Mev gamma rays, which simulates reasonably well a surface covered with fission products.

*Data from *The Effects of Nuclear Weapons.*[24]

Table 16—SHIELDING FACTORS FOR TYPICAL LIGHT RESIDENTIAL STRUCTURES AGAINST GAMMA RAYS SIMULATING PENETRATING RESIDUAL RADIATION

		Reduction factors*			
Structure	Location	Roof contribution	Ground contribution	Total	Protection factor†
Two-story wood-frame house‡	2nd floor, center	0.076	0.50	0.58	1.7
	1st floor, center	0.034	0.57	0.60	1.7
	Basement, center	0.015	0.028	0.043	23§
	Basement, corner				40¶
	Basement, corner shelter				<100¶
One-story wood rambler‡	1st floor, center	0.10	0.54	0.64	1.6
Two-story brick veneer‡	1st floor, center	0.034	0.14	0.17	6**
	Basement, center	0.015	0.021	0.036	28§
Shelter (earth covered) 3 ft below grade††					1000 or more

*Reduction factor represents the dose rate at a specified location divided by the dose rate outside at 3 ft above ground.

†Protection factor represents the outside dose rate at 3 ft above ground divided by the dose rate inside at the specified location.

‡After Eisenhauer.[18]

§Applies to basement with no exposed walls.

¶After Auxier;[1] Auxier, Buchanan, Eisenhauer, and Menker;[2] and Strickler and Auxier.[39]

**Applies only for detector locations below window sill.

††From *The Effects of Nuclear Weapons.*[24]

Table 17—APPROXIMATE ATTENUATION FACTORS FOR GAMMA RAYS FROM FISSION PRODUCTS AS A FUNCTION OF SHIELD THICKNESS FOR INDICATED MATERIALS*

	Shield thickness for indicated materials, in.					
Attenuation factor	Lead (710 lb/cu ft)	Iron and steel (490 lb/cu ft)	Concrete (144 lb/cu ft)	Earth (100 lb/cu ft)	Water (62.4 lb/cu ft)	Wood (Fir) (3.4 lb/cu ft)
2	0.28	0.7	2.5	3.5	4.8	9.2
4	0.64	1.8	6.6	8.9	13	25
10	1.0	2.7	9.7	13	19	36
50	1.6	4.2	14	20	29	55
100	1.9	4.8	16	23	33	62
1,000	2.7	6.8	22	32	45	88
10,000	3.5	8.8	27	39	56	110
100,000	4.3	11	32	46	70	140

*Data from *The Effects of Nuclear Weapons.*[24]

deal on the maximal overpressure, the rate of pressure development (time to $P_{max.}$), the character of the rising (and under certain circumstances the falling) portions of the pressure curve, and the duration of the overpressure. In general, biologic tolerance to long-duration overpressures going to $P_{max.}$ instantaneously, ("long" and "instantaneously" being used relatively), as occurs when a shock wave accompanies the advancing pressure pulse, is a function mostly of the overpressure. In contrast, for short-duration fast-rising pulses, the duration as well as the magnitude of the overpressure is critical, e.g., the shorter the duration, the greater the overpressure required to produce a given level of damage. The interval over which variation in the duration is significant apparently depends upon the size of the animal and is not known with certainty for each species. However, the definitive values for duration are like hundreds of microseconds* to a few milliseconds* for smaller animals and many to a few tens of milliseconds for the larger animals.

Damaging and fatal conditions for man are not clearly defined. However, tentative estimates for carefully delineated conditions can be set forth based on animal experiments and on a few instances of human exposure.

Fast-rising Overpressures of Long Duration: Nuclear detonations produce blast overpressures much longer in duration than those obtained with high explosives; e.g., like 0.5 to many seconds for the former and 1 to 20 msec for the latter. Under conditions of exposure in which pressures are applied almost instantaneously, such as might be the case for a target located against a solid surface where an incident and reflected overpressure could envelop the animal practically simultaneously, biologic tolerance is relatively low. Table 18 shows data for several species of animals exposed against a steel plate closing the end of a shock tube. Overpressures rose sharply in a few tens of microseconds (millionths of a second) and endured several seconds for the smaller animals but only 400 msec in the experiments with dogs. A tentative estimate of man's tolerance, if exposed under similar conditions to overpressures enduring longer than 0.5 sec, is also included in the table.

Slowly Rising Overpressures of Long Duration: In marked contrast is the much greater tolerance of mammals to slowly rising overpressures of long duration. Table 19 shows sample data obtained using a shock tube wherein the time $P_{max.}$ varied from about 30 to 150 msec. Although the overpressures reached as high as 170 psi and endured from 5 to 20 secs, there were no fatalities, and lung damage was minimal. Fatal conditions for such exposure are not known either for experimental animals or for man, but it is very likely that slowly developing overpressures to well over 100 psi, such as might occur in large areas being pressurized through small openings, would not prove very hazardous to man if missile impact and displacement by blast winds were avoided.

Orbital Fracture: Although slowly rising overpressures well above 100 psi may not prove fatal to man, a word of caution is indicated because eight instances of orbital fracture into the sphenoid and ethmoid sinuses have been observed in dogs subjected to long-duration overpressures ranging from about 140 to 240 psi when the time to $P_{max.}$ has been less than 30 msec. Such observations were incidental to shock-tube experiments, and the details are summarized in Table 20. To date, no similar lesions have been described in other pressurized animals or in man. However, blow-out fracture of the floor of the orbit into the maxillary sinuses has been observed by Smith and Regan[37] in humans following the delivery of a blow to the eye with a blunt object. Consequently, the application of pressure to the eye at a rate that outstrips the flow of gas into the sinuses to counter the hydraulic load applied to the orbital wall may well cause a serious blast lesion in man.

Stepwise Fast-rising Overpressures of Long Duration: Mammalian tolerance to overpressures of long duration in which the rising component of the pressure consists of two fast-rising steps is intermediate between that noted in the previous two sections. Simply exposing an animal at various distances away from, rather than against, a plate closing the

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*Microsecond = 1/1,000,000 sec; millisecond = 1/1,000 sec.

Table 18—SHOCK-TUBE MORTALITY DATA FOR FAST-RISING LONG-DURATION OVERPRESSURES WHEN INCIDENT AND REFLECTED PRESSURES ARE APPLIED ALMOST SIMULTANEOUSLY*

Animal species	Overpressure for indicated mortality, psi						Threshold pressure for lung injury, psi	
	1 per cent		50 per cent		99 per cent			
	Incident	Reflected	Incident	Reflected	Incident	Reflected	Incident	Reflected
Mouse†	7	20	11	30	15	44	4	10
Rabbit†	9	25	12	33	15	44	6	15
Guinea pig†	10	28	13	37	16	48	6	15
Rat†	10	28	14	39	18	53	8	19
Dog‡	15	40	17	48	20	56	7	20
Man§		35–45		45–55		55–65		15–25

NOTE: All incident and reflected overpressures were empirically determined. Because of geometric factors there necessarily was not the same relation between incident and reflected overpressures for experiments with the smaller and the larger animals; e.g., the reflection of a given incident pressure is less in the presence of a larger animal than it is for the smaller animal.

*Reports WT-1467,[30] TID-6056,[31] TID-5564,[44] and unpublished data from an AEC project being conducted at Lovelace Foundation, Albuquerque, N. Mex.

†Durations of overpressure were 6–8 sec.

‡Durations of overpressure were 400 msec.

§Tentative estimate for overpressure durations greater than 500 msec.

Table 19—EXPOSURE TO SLOW-RISING OVERPRESSURES OF LONG DURATION*

Max. overpressure, psi	Time to max. pressure, msec	Duration of overpressure, sec	Damage observed		
			Ruptured eardrums	Hemorrhagic sinuses	Lung contusion
167	155	5	Yes	Yes	None
118	85	20	Yes	Yes	None
156	86	20	Yes	Yes	Minimal
170	60	10	Yes	Yes	None
86	28	10	Yes	Yes	None
130	30	10	Yes	Yes	Minimal

*Richmond et al.[32]

Table 20—ORBITAL FRACTURE IN DOGS EXPOSED TO SLOW-RISING LONG-DURATION OVERPRESSURES*

Over-pressure, psi	Occurrence of orbital fracture for indicated times to maximal pressure (P_{max})											
	10 to 20 msec			21 to 30 msec			Totals 10 to 30 msec			Totals 31 to 160 msec		
	Number animals	Orbital fracture	% fracture	Number animals	Orbital fracture	% fracture	Number animals	Orbital fracture	% fracture	Number animals	Orbital fracture	% fracture
40–80				2	0	0	2	0	0	3	0	0
81–120	1	0	0	10	0	0	11	0	0	4	0	0
121–160	5	1	20	6	0	0	11	1	9	6	0	0
161–200	1	1	100	9	3	33	10	4	40	3	0	0
201–240	2	2	100	1	1	100	3	3	100	0	0	0
Totals	9	4	44	28	4	14	37	8	22	16	0	0

Overpressure durations ranged from 5 to 20 sec. Data from Richmond, AEC Project, Lovelace Foundation, Albuquerque, N. Mex. (unpublished) end of a shock tube raises the P_{50} reflected pressure in the case of the guinea pig, for example, from about 37 to near 57 psi when the animal is exposed against and at 12 in. from the end plate, respectively. Table 21 shows the detailed data. When the animal was exposed away from the end plate, the steep incident pressure enveloped and passed the animal and struck the end plate; then the fast-rising reflected overpressure reached and passed back over the animal. The time between the arrival of the incident and reflected pulses was proportional to the distance the animal was located from the end plate, being about 1.4 msec when the distance was 1 ft.

Tolerance of man under such circumstances is not known for long-duration overpressures, but estimates for conditions involving short-duration incident and reflected pressures wherein human fatality occurred have been published. Such data along with related short-duration experiments with animals will now be noted.

Fast-rising Overpressures of Short Duration: Desaga[16] described the exposure of 13 men in an open-topped antiaircraft gun emplacement to blast produced by high-explosive bombs. Two individuals situated in a corner close to the walls were fatally injured. The incident and maximum reflected overpressures of probably 10 to 20 msec duration were estimated at 58 and 235 psi, respectively.

For exposures to single short-duration sharp-rising pressure pulses produced by high explosives not involving reflections from nearby surfaces, tolerance varies with the duration of the incident overpressure, as shown by Table 22, which shows the just-fatal conditions for dogs. The magnitudes of the pressures that reflected from the target animals are not known. Neither is the pressure-duration relationship known for dog mortality when the durations of single fast-rising overpressures are longer than about 12 msec, with the exception of the mortality figures at 400-msec duration given in Table 18.

There has been no complete systematic study of the critical pressure-duration factors applying to single fast-rising overpressures as these influence mortality in various species of animals. Available data, much of a tentative nature, from recent experiments are summarized in Table 23. The P_{50} figures for the short- and long-duration overpressures were not statistically different, although those for the rabbit approached statistical reliability.

Thus, there is accumulating evidence that overpressure duration beyond 5 msec will not lower the overpressures for a given mortality in animals up to the size of a rabbit, but it will do so in animals the size of dogs and probably man. Conversely, shortening the duration much below 5 msec does remarkably increase the overpressure associated with a given mortality for dogs and, no doubt, also for man and the several smaller species of experimental animals. These remarks are consistent with past reports of work done in England,[20,21] Germany[3,16,35] and Sweden.[11,12]

Eardrums: Although eardrum rupture under emergency conditions is not in itself a serious injury, it is well to set forth the available data. Tolerance of the tympanic membranes of animals exposed to blast overpressures at the Nevada Test Site correlated fairly well with the maximum overpressure. The data are summarized in Table 24, which also shows results noted by Zalewski[47] in experiments on human cadavers.

Secondary (Missile) Effects

Penetrating: The impact-velocity relationships for glass fragments to pass through the body wall of dogs and reach the abdominal cavity are shown in Table 25; Table 26 notes the threshold for penetrating wounds and skeletal fracture determined with bullets by Journée[27] using human material. Stewart[38] recently determined the ballistic limit of the eye of a rabbit to steel spheres and cubes that were impacted against the fresh eyeball fixed in a large block of gelatin. The velocities associated with a 50 per cent chance of puncturing the cornea, conjuctiva, or sclerotic coat, causing loss of aqueous humor, are given in Table 27. Such wounds require expert medical attention to control infection and avoid loss of sight. The tolerance of the eye to impact from small glass fragments is not known for either the animal or the human case. The data in Table 27 are the only quantitative figures for missile damage to the eye known to the authors. Obviously, they

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*P_{50} = the pressure associated with 50 per cent mortality.

Table 21—MORTALITY DATA FOR GUINEA PIGS EXPOSED AGAINST, AND AT VARIOUS DISTANCES FROM, THE END PLATE CLOSING A SHOCK TUBE TO FAST-RISING LONG-DURATION OVERPRESSURES WHEN THE INCIDENT AND REFLECTED OVERPRESSURES ARE APPLIED IN TWO STEPS*

Distance from end plate, in.	Number animals	Overpressure† associated with 50% mortality, psi		Time between application of incident and reflected pressures, msec
		Incident	Reflected	
0	140	12.1	36.7 ± 0.7	Essentially none
1	75	13.4	40.8 ± 2.1	0.10
2	78	15.6	48.3 ± 1.3	0.20
3	87	16.9	52.8 ± 1.9	0.30
6	99	18.7	58.6 ± 1.6	0.63
12	109	18.2	57.1 ± 1.1	1.36

*Report TID-6056.[31]

†The overpressure durations were between 6 and 8 sec.

Table 22—FAST-RISING SHORT-DURATION OVERPRESSURES REQUIRED FOR NEAR 100 PER CENT MORTALITY IN DOGS*

Maximum static overpressure, psi	Overpressure duration, msec
216	1.6
219	1.6
125	4.1
85	8.6
79	10.3
76	11.8

*Data from Desaga.[16]

Table 23—RELATION BETWEEN OVERPRESSURE AND 50 PER CENT MORTALITY FOR ANIMALS EXPOSED TO SINGLE SHARP-RISING OVERPRESSURES OF INDICATED DURATIONS*

Animal species†	Overpressures for 50% mortality at indicated durations, psi							
	6 to 8 sec		400 msec (t)‡		80 msec (t)‡		3 to 4 msec	
	Incident	Reflected	Incident	Reflected	Incident	Reflected	Incident	Reflected
Mouse	11	30	11	31			11	29
Rabbit	12	33	12	33			13	36
Guinea pig	13	37	13	35	14	38	13	35
Rat	14	39	14	37			11	39
Dog			17	48				

*Data from Report TID-6056[31] and unpublished work, AEC Project, Lovelace Foundation, Albuquerque, N. Mex.

†Animals exposed against the end plate closing a shock tube to incident and reflected overpressures that were applied almost instantaneously.

‡(t) = tentative data.

Table 24—PRESSURE TOLERANCE OF THE EARDRUMS OF DOG AND MAN

	Maximum pressures for the noted conditions		
Species	Minimal, psi	Average, psi	Maximal, psi
Dog*	5	31	90
Man†	5	20–33	43

*Data from 1953, 1955, and 1957 Nevada Field Tests; see WT-1467.[30]

†Data from Zalewski.[47] Human eardrum tolerance varies with age, hence the variation from 33 psi (for ages 1 to 10 years) to 20 psi (for ages above 20 years). See also Report TID-5564.[44]

Table 25—VELOCITY-MASS PROBABILITY RELATIONSHIPS REQUIRED FOR SMALL WINDOW-GLASS FRAGMENTS TO TRAVERSE THE ABDOMINAL WALL AND REACH THE PERITONEAL CAVITY OF DOGS*

Mass of glass fragments, g	Impact velocities for indicated probabilities of penetration in per cent, ft/sec		
	1 per cent	50 per cent	99 per cent
0.05	320	570	1000
0.1	235	410	730
0.5	160	275	485
1.0	140	245	430
10.0	115	180	355

*Data from Report AECU-3350.[6]

Table 26—EFFECTS OF MISSILES ON HUMAN CADAVERS*

Type missile	Mass, g	Velocity, ft/sec	Effect on man
Spherical bullets	8.7	190	Slight skin laceration
	8.7	230	Penetrating wound
	7.4	360	Abrasion and crack of tibia
	7.4	513	Travels through thigh
Bullets	6–10	420–266	Threshold for bone injury
	6–15	751–476	Fractures large bones

*Data from Journée.[27]

Table 27—IMPACT VELOCITY REQUIRED FOR PUNCTURING RABBIT EYEBALL EMBEDDED IN GELATIN*

Shape of steel missile	Mass		V_{50} impact velocity, ft/sec	Effect on rabbit eye
	Grains	Grams		
Sphere	0.85	0.06	350	Fifty per cent chance of puncturing wall of eyeball with loss of aqueous humor (fluid).
Sphere	16.0	1.04	152	
Cube	2.1	0.14	205	
Cube	4.2	0.27	123	
Cube	16.0	1.04	119	
Cube	64.0	4.15	73	
Cube	255.0	16.52	93	

*Data from Stewart, Report CWLR 2332.[38]

should be used with caution since damage at lower velocities could well occur were the eye in situ and surrounded by the fairly rigid boney orbit.

Nonpenetrating: Some appreciation of the biological effects of nonpenetrating missiles can be obtained by consulting Table 28. The table gives data regarding chest damage in dogs from the impact of missiles against the thoracic wall and the range of impact velocities over which human skull fracture[25] can be anticipated if the head were struck with an object weighing about 10 lb (near the average weight of the human head).

Tertiary (Displacement) Effects

It is likely that most injuries associated with displacement by blast winds will occur during decelerative impact with some hard object. Table 29 gives data from relevant animal experiments with an extrapolation to man along with a comparison with automobile-accident statistics.[15] Table 30 sets forth impact velocities for experimental fracture of the human skull, feet, and spine. Although the impact velocities are low for severe injury to humans when deceleration is abrupt and occurs over a very short distance, survival of man from falls involving 80- to 90-mph velocities has been described when the deceleration was less rapid and occurred over distances of several inches.[14]

THERMAL EFFECTS

Skin Burns: The thermal energies required to burn exposed human skin are related to explosive yield. A given amount of energy, if applied quickly, produces a more severe burn than the same energy applied slowly. A consequence of this is the fact that the energy required to produce burns of the same severity is greater for the larger than the smaller yield explosions since the former apply energy more slowly. Table 31 summarizes the approximate relation between thermal energy and skin burns for bare white skin. Table 32, assembled from the data of Evans et al.[19] and Brooks et al.,[7] shows that much lower thermal energies are required to burn the skin of Negro volunteers compared with white volunteers.

Extent of Burn and Mortality: It is instructive to note that mortality in burn cases on the average varies with the extent of the total area of the body affected. Table 33, assembled from smoothed data cited by Schwartz et al.[36] on 405 treated cases, shows the approximate empirical relation between mortality and the percentage of the body area burned. Fifty per cent mortality was, on the average, associated with a burn involving 65 per cent of the total body area. Analytical work on the data allowed the authors to tabulate figures giving some indication of the influence of the severity of the burn on mortality. Table 34 shows the relative importance of concomitant second- and third-degree burns associated with 50 per cent mortality. Roughly 50 per cent of properly treated individuals will survive a second- and third-degree burn involving nearly 85 and 46 per cent of the total body area, respectively.

Healing Time of Experimental Burns: The healing time of small experimental burns in humans has been reported by Butterfield et al.[8] to involve times like 8, 16, and 25 days for first-, second-, and third-degree burns, respectively, providing infection did not occur. Since second- and third-degree burns for all practical purposes will involve infection, early therapy is essential. Clean second-degree burns usually heal by epithelization, but, if infection ensues, healing may take up to six weeks. Very small third-degree burns heal by scar formation, but, if the burn is more than 2 cm across, skin grafting is usually essential. Extensive third-degree burns require prolonged plastic repair involving hospitalization for many months. Attention is directed to Table 35, compiled from the excellent study of Butterfield et al.[8] mentioned earlier, for a summary of the above remarks along with simplified relevant data.

Flash Blindness: Byrnes[9] has stated that temporary loss of vision can be expected as far away as 35 miles from the night detonation of a 20-kt nuclear device.

Retinal Burns: Retinal burns, according to Byrnes,[9] can occur as far away as 35 miles from a 20-kt nuclear detonation in clear weather. There is more of a hazard at night because the pupil is dilated. Ham et al.[26] have estimated that threshold lesions to the human retina could occur at 9 to 14 miles from a 1- to 100-kt night detonation when visibility was 25 miles and if the eye were completely dark-adapted and the blink reflex excluded all light after 150 msec.

Table 28—EFFECTS OF MISSILE IMPACT ON THE CHEST AND HEAD

Biological effects observed	Threshold velocities for missiles of indicated weights, ft/sec 0.8 lb	0.4 lb
Lung hemorrhages:*		
Side of impact only (unilateral)	45	80
Impact side and opposite side (bilateral)	110	125
Rib fracture*	60	120
Internal lacerations from fractured ribs*	90	120
Fatality within 1 hr*	155	170
Experimental fracture human skull†	15 to 23 ft/sec range of velocities for 10 lb object (7-15 lb weight range of human adult head)	

*Unpublished data from dogs, AEC Project, Lovelace Foundation, Albuquerque, N. Mex.
†Computed from data of Gurdjian, Webster, and Lissner.[25]

Table 29—VELOCITIES OF IMPACT AGAINST A HARD SURFACE ASSOCIATED WITH 50 PER CENT MORTALITY OF THE INDICATED SPECIES OF ANIMALS WITH EXTRAPOLATION TO MAN*†

Species of animal	Average animal mass, g	Impact velocity for 50 per cent mortality Ft/sec	Mph	Equivalent height of fall (approx.), ft
Mouse	19	38	26	22
Rat	180	44	30	30
Guinea pig	650	31	21	15
Rabbit	2,600	31	21	15
Man (computed)	72,574 (160 lb)	27	18	11

NOTE: The regression equation fitted to the animal data and used in computing the predicted V_{50} for man is

$$\log V_{50} = 1.6792 - 0.517 \log \overline{m}$$

V_{50} = velocity associated with 50 per cent mortality in feet per second and $\overline{m}$ = average weight of the animal in grams. Standard error for estimating V_{50} is 0.0448 log units or about 10.5 per cent.

*National Safety Council release on urban automobile accidents shows 40 and 70 per cent of fatalities were associated, respectively, with speeds of or less than 20 and 30 mph.—Quoted from DeHaven.[15]

†Data AEC Project, Lovelace Foundation, Albuquerque, N. Mex.

Table 30—APPROXIMATE IMPACT VELOCITIES AND EQUIVALENT HEIGHTS OF DROP FOR FRACTURE OF HUMAN SPINE, SKULL, FEET, AND ANKLES

Effects on man	Impact velocity Ft/sec	Mph	Equivalent height of drop, in.	Comment
Experimental skull fracture*	13.5–22.9	9.5–15.0	37–91	Range of 1 to 99 per cent fracture of cadaver heads dropped on flat metal surface
Fracture of feet and ankles†	12–13	8–9	25–30	Impact-table data using cadavers with knees locked
Fracture of lumbar spine‡	8	6	12	Estimated for impact on hard surface in sitting position

*Data from Gurdjian, Webster, and Lissner.[25]
†Data from Draeger et al.[17]
‡Computed from data of Ruff.[34]

Table 31—THERMAL ENERGIES FOR BURNS OF BARE WHITE SKIN*

Degree of burn	Thermal energy for the indicated explosive yields, cal/cm^2 1 kt	20 kt	100 kt	1 Mt	10 Mt	20 Mt
First degree	2.0	2.5	2.7	3.2	3.7	3.8
Second degree	4.1	4.9	5.4	6.2	7.2	7.5
Third degree	6.0	7.3	8.1	9.4	10.8	11.4

*Data from *The Effects of Nuclear Weapons.*[24]

Table 32—COMPARISON OF THERMAL ENERGIES APPLIED OVER 540 MSEC REQUIRED FOR BURNS OF THE SKIN OF WHITE AND NEGRO VOLUNTEERS*

	Thermal energy, cal/cm^2	
Degree of burn	White subjects	Negro subjects
None	2.0	Not stated
First degree	3.2	Not stated
Second degree	3.9	1.8–2.9
Third degree	4.8	3.3–3.7

*Data from Evans et al.[19] and Brooks et al.[7]

Table 33—MORTALITY IN TREATED BURN CASES RELATED TO PERCENTAGE OF BODY AREA BURNED*†

Average mortality read from probit curve, %	Area burned, % of total body area
1	22
10	41
20	49
30	55
40	60
50	65
60	70
70	75
80	81
90	89
95	96

*Number of cases, 405.

†Data from Schwartz, Soroff, Reiss, and Curtis, Report MEDEW-RS-12-56.[36]

Table 34—ESTIMATED RELATIVE IMPORTANCE OF CONCOMITANT SECOND- AND THIRD-DEGREE BURNS ASSOCIATED WITH AN AVERAGE MORTALITY OF 50 PER CENT IN TREATED CASES*†

Third-degree burn area, %	Second-degree burn area, %	Third-degree burn area, %	Second-degree burn area, %
46	0	20	48
40	11	15	57
35	21	10	67
30	30	5	76
25	39	0	85

*Number of cases, 405.

†Data from Schwartz, Soroff, Reiss, and Curtis, Report MEDEW-RS-12-56.[36]

Table 35—ESTIMATED HEALING TIME FOR FIRST-, SECOND-, AND THIRD-DEGREE BURNS AND SIMPLIFIED CLINICAL COMMENTS*

Degree of burn	Healing time, days	Comments
First	8	Burning pain 24 hr; soreness and redness 8 days
Second	8–16 (uninfected)	Intense burning pain 24 hr; swelling by 1 hr (can be very serious if face is involved)
	Up to 42 (infected)	Blistering 2 to 30 hr; ooze serum 3–4 days; scar (scabbing) 6 to 10 days; aching and tenderness 8–14 days
Third	20 to 30 (uninfected small burns epithelize)	Brief intense pain followed by blanching and subsequent insensitiveness to pin prick; swelling up to 2 days (can be very serious if eyes and lips are involved); blistering around third-degree burn, 24–36 hrs; soreness 7–10 days
	20 to 42 (larger burns healing with scar formation)	Separation of destroyed skin 3 to 4 weeks with ulceration; epithelization 4 weeks (small burns); scar formation 6 weeks; areas wider than 2 cm (0.8 in.) require plastic surgery
	Many months (skin grafting required)	

*Data from Butterfield, Seager, Dixey, and Treadwell.[8]

Table 36—PROBABLE EFFECTS IN HUMANS OF ACUTE EXPOSURE TO IONIZING RADIATION OVER THE WHOLE BODY*

Acute dose, r	Probable effect
0–25	No obvious injury
25–50	No serious injury; possible blood changes
50–100	Blood-cell changes; some injury; no disability
100–200	Injury; possible disability
200–400	Injury and disability certain; death possible
400	Fatal to 50 per cent
600 or more	Fatal

*Data from *Radiological Health Handbook*, U. S. Department of Health, Education and Welfare,[28] citing *The Effects of Nuclear Weapons*[24] as the source of the information.

Appreciation of the hazard to man from retinal burns resulting from fireball light is apparently far from complete, particularly for bursts above or in the high terrestrial atmosphere. However, a few data are at hand from experience during Operation Hardtack in 1958* when two devices in the megaton range were detonated in the vicinity of Johnston Island, one at an altitude of about 100,000 ft and the other above 200,000 ft. The latter explosion did not produce an intensity of thermal radiation on the earth's surface at Johnston Island sufficient to produce first-degree burns in humans. No data were obtained from the lower explosion because of cloud cover. A biomedical project employing rabbits to investigate the hazard of burns to the retinal tissue of the eye observed retinal burns (0.5 mm) out to distances of 345 miles. This involved a potential hazardous area of near 374,000 square miles in clear weather. It was concluded that an individual would have to be looking directly at the fireball of a nuclear detonation to receive permanent, serious impairment of vision from a high-altitude burst.

IONIZING-RADIATION EFFECTS

Acute Exposure: The probable early effects in humans of acute exposure to varying doses of ionizing radiation over the whole body are listed in Table 36.[28]

Chronic Exposure: If exposure to radiation is not acute but is prolonged, some tissues of the body undergo repair, and the degree of the biological effect depends, among other things, upon the balance maintained between the continuing repair and radiation damage. For doses accumulated over a one- or two-day period, the repair process is not very effective, but, on and after the third day, particularly at low dose rates, very appreciable differences occur. Tables 37 and 38 summarize applicable estimates made by the U. S. Public Health Service.[28]

Accumulative Genetic Effects: Long-term genetic effects attributable to exposure to ionizing radiation above the natural background (4.3 to 5.5 r over 30 years in the United States) are not clearly definable. However, responsible individuals have estimated that from 30 to 80 r accumulated dose would double the mutations that occur spontaneously. In view of this, a Genetics Committee of the National Academy of Sciences[50] has recommended that radiation exposure (1) be held as low as possible, (2) as an average for the population, be limited to not more than 10 r accumulated dose to the reproductive organs up to the age of 30 years, and (3) be limited for individuals to 50 r to the reproductive organs up to age 30 and to 50 r additional up to the age 40.

Emergency Exposure: It is of interest to note here that a responsible body of scientists has considered the question of the maximal permissible radiation exposure in case of an emergency. The following statement was made: However, it can be stated with some confidence that total doses of 150 to 200 r, delivered acutely or over days or months, would result in no apparent acute effects and serious late effects in only a small percent of those exposed."†

Hospitalization: Such an opinion is consistent with experience gained in human radiation accidents and treatment summarized by Gerstner.[22,23] This author also noted the percentage of the exposed population that might require hospitalization. The data, along with a very general assessment of the clinical course, are noted in Table 39.

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*Joint AEC-DOD News Release, dated June 15, 1959.[52]

†National Academy of Sciences—National Research Council Report, *The Adequacy of Government Research Programs in Nonmilitary Defense*, p. 17, 1958.[51]

Table 37—ESTIMATE OF EFFECTIVE DOSE AND LETHALITY OF VARIOUS DOSE RATES TO MAN*†

Dose. r/day	Day	Accumulated dose, r	Effective accumulated dose, r	Estimated mean survival time, days	Estimated percentage of deaths in 30 days
200	1	200	200		30
	3	600	542	20	60
	5	1000	819	15	85
	10	2000	1326	10	100
100	1	100	100		8
	3	300	271		35
	5	500	409	15	50
	10	1000	663	15	75
50	1	50	50		0
	3	150	135		15
	5	250	204	30	25
	10	500	330	30	40
	15	750	395	30	50

*From *Radiological Health Handbook.*[28]

†Based on 250-kvp X rays. Corrections should be made for higher energy radiations; e.g., 1000-kvp X or gamma radiation would have a relative biological effectiveness of approximately 70 per cent of 250-kvp X rays.

Table 38—ESTIMATED DOSES FOR VARYING DEGREES OF INJURY TO MAN*†

Dose rate, r/day	Period of time	Effect
500	2 days	Mortality close to 100 per cent
100	Until death	Mean survival time approximately 15 days 100 per cent mortality in 30 days
60	10 days	Morbidity and mortality high with crippling disabilities
30	10 days	Disability moderate
10	365 days	Some deaths
3	Few months	No drop in efficiency
0.5	Many months	No large-scale drop in life span

*From *Radiological Health Handbook.*[28]

†Based on 250-kvp X rays. Corrections should be made for higher energy radiations; e.g., 1000-kvp X or gamma radiation would have a relative biological effectiveness of approximately 70 per cent of 250-kvp X rays.

Table 39—ESTIMATED CLINICAL COURSE AND HOSPITILIZATION REQUIREMENTS FOR HUMANS EXPOSED TO VARIOUS ACUTE DOSES OF PENETRATING RADIATION*

Dose, r	Individuals following indicated clinical symptoms, % Trivial	Light	Moderate	Serious	Grave	Fatal	Individuals needing hospitilization, %	Maximal time of hospitilization, weeks
0–200	98	2					None	0
200–300	1	33	64	2			2	6
300–400			6	68	26		94	7
400–500				3	58	39	100	9
500–600					6	94	100	11
Above 600						100	100	11

*Compiled from Gerstner.[22,23]

QUANTITATIVE WEAPONS-EFFECTS DATA

The material that follows, along with the explanatory remarks for each table or illustration, sets forth selected weapons-effects data, all referable to sea-level surface altitudes, as a function of explosive yield for surface and typical air bursts. Some assessment of the comparative hazard to man from blast, thermal radiation, and ionizing radiation can be obtained by referring to previous sections of the brochure.

Perhaps the reader will share with the authors the conclusion that planned protection from weapon-produced variations in the environment is desirable and that provision of such protection would markedly enhance the chances of survival for a high percentage of the population should nuclear war ever occur.

TABLE 40: WEAPONS-EFFECTS DATA FOR SELECTED PARAMETERS

In Table 40 are tabulated the approximate ranges from Ground Zero (GZ) and the circular areas over which the indicated selected weapons effects may occur as a function of explosive yield. It was assumed that slant ranges for initial ionizing radiation and thermal data are a reasonable approximation of the ground range and that atmospheric conditions were clear. (Data are from *Effects of Nuclear Weapons.*[24])

	Explosive yield					
Selected parameters	1 kt	20 kt	100 kt	1 Mt	10 Mt	20 Mt
	Range from GZ for Various Parameters, Miles					
700 rem (initial)	0.42	0.70	0.96	1.44	2.04	2.27
100 rem (initial)	0.62	0.99	1.29	1.81	2.55	2.88
30 rem (initial)	0.74	1.18	1.51	2.07	2.91	3.30
5 psi (typical air burst)	0.39	1.06	1.81	3.90	8.40	10.6
5 psi (surface burst)	0.28	0.77	1.32	2.85	6.14	7.74
1 psi (typical air burst)	1.00	2.71	4.64	10.0	21.5	27.1
1 psi (surface burst)	0.86	2.35	4.02	8.65	18.6	23.5
Second-degree burns	0.48	1.72	3.40	9.00	23.8	31.9
First-degree burns	0.69	2.47	4.97	13.3	36.0	49.2
Fireball	0.044	0.14	0.28	0.69	1.7	2.3
Crater (surface burst, dry soil)	0.012	0.031	0.058	0.12	0.26	0.32
	Area Corresponding to Above Ranges, Square Miles					
700 rem (initial)	0.55	1.54	2.90	6.51	13.1	16.2
100 rem (initial)	1.21	3.08	5.23	10.3	20.4	26.1
30 rem (initial)	1.72	4.37	7.16	13.5	26.6	34.2
5 psi (typical air burst)	0.48	3.53	10.3	47.8	222	353
5 psi (surface burst)	0.25	1.86	5.47	25.5	119	189
1 psi (typical air burst)	3.14	23.1	67.6	314	1450	2310
1 psi (surface burst)	2.32	17.4	50.8	235	1090	1730
Second-degree burns	0.73	9.29	36.3	254	1780	3200
First-degree burns	1.50	19.2	77.6	556	4070	7600
Fireball	0.006	0.062	0.25	1.50	9.08	16.6
Crater (surface burst, dry soil)	0.00045	0.0012	0.0096	0.045	0.21	0.32

TABLE 41: COMPARATIVE WEAPONS-EFFECTS DATA

Table 41 gives the approximate ground ranges in miles for selected values of initial ionizing radiation, overpressure, and thermal radiation computed for typical air bursts of indicated yields assembled in such a way as to aid appreciation of the interrelation between the individual effects. For example, a ground range of about 3 miles is shown for 100-rem initial radiation from a 20-Mt detonation; at this distance an overpressure near 19 psi can be expected along with a thermal load of over 1000 cal/cm^2. Ten miles from GZ, 1 psi is predicted for a 1-Mt explosion; at this location there would occur less than 10 rem and about 6 cal/cm^2 of initial ionizing and thermal radiation, respectively. Referring to Table 31, one can see that 6 cal/cm^2 of thermal energy is sufficient to produce second-degree burns to the exposed bare skin.

Since the data in Table 41 are for typical air bursts, no significant short-term fallout hazard would occur. As in the previous table, slant ranges for ionizing and thermal radiations were considered to be a reasonable approximation of the ground range.

The symbols > and ≫ mean greater than and much greater than, < and ≪ mean less than and much less than, respectively.

(Data are from *Effects of Nuclear Weapons.*[24])

Initial ionizing radiation, overpressure, and thermal radiation	1 kt	20 kt	100 kt	1 Mt	10 Mt	20 Mt
30-rem range, miles	0.74	1.18	1.51	2.07	2.91	3.30
Pressure, psi	1.70	4.16	6.60	11.1	15.6	17.0
Thermal, cal/cm^2	1.70.	12.4	36.0	182	880	>1000
100-rem range, miles	0.62	0.99	1.29	1.81	2.55	2.88
Pressure, psi	2.30	5.55	8.30	12.4	17.4	18.8
Thermal, cal/cm^2	2.50	18.0	52.0	240	>1000	>1000
700-rem range, miles	0.42	0.70	0.96	1.44	2.04	2.27
Pressure, psi	4.3	9.1	11.2	14.9	20.5	22.5
Thermal, cal/cm^2	6.9	38	97	400	>1000	>1000
1-psi range, miles	1.00	2.71	4.64	10.0	21.5	27.1
Radiation, rem	<10	<10	<10	<10	≪10	≪10
Thermal, cal/cm^2	0.88	2.02	3.30	5.90	11.4	13.8
5-psi range, miles	0.39	1.06	1.81	3.90	8.40	10.6
Radiation, rem	900	64	<10	<10	<10	<10
Thermal, cal/cm^2	7.00	15.8	24.5	46.0	89.0	105
Second-degree burn:						
Range, miles	0.48	1.72	3.40	9.00	23.8	31.9
Pressure, psi	3.6	2.2	1.7	1.2	<1	<1
Radiation, rem	380	<10	<10	<10	≪10	≪10

FIGURE 3: ENVIRONMENTAL VARIATIONS DUE TO BLAST, THERMAL RADIATION, AND IONIZING RADIATION FOR INDICATED EXPLOSIVE YIELDS

The scaled ranges and areas applicable to 100 rem of initial radiation, 1 psi, and second-degree burns for typical air bursts are shown in Fig. 3 as these parameters vary with explosive yield. The relative gain in range and areas covered by blast and thermal effects compared with initial ionizing radiation as weapon weight increases deserves emphasis. For yields of 1 Mt or less, the areas in which at least second-degree burns will occur are smaller than those for at least 1-psi overpressure; whereas for the higher yields the reverse is true. Slant ranges for ionizing and thermal radiation were assumed to be reasonable approximations of the ground range. (Data are from *Effects of Nuclear Weapons*.[24])

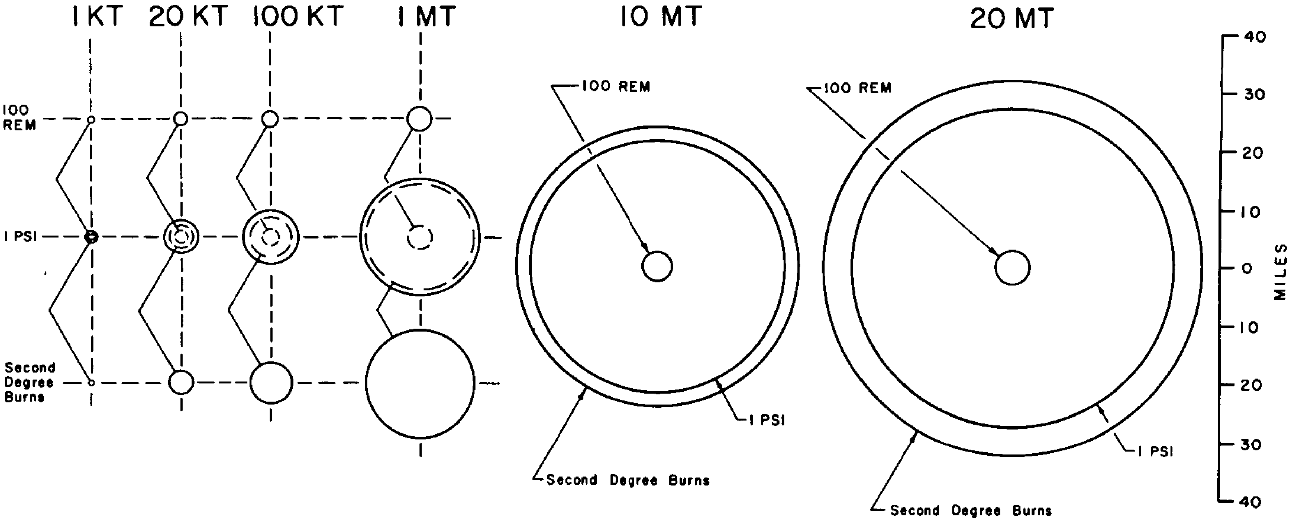


FIGURE 4: ENVIRONMENTAL VARIATIONS DUE TO BLAST, THERMAL RADIATION, AND INITIAL IONIZING RADIATION FOR 1-, 20-, 100-, AND 1000-KT EXPLOSIVE YIELDS

The scaling relations for 30 and 100 rem of initial radiation, 1 and 5 psi, and second-degree burns are shown to the same scale in Fig. 4 for typical air bursts ranging from 1 kt to 1 Mt. The reader will note that the 100-rem radius extends well beyond the 5-psi line for a 1-kt yield. These two radii are almost equal for 20 kt, but the 5-psi line extends much beyond the 100-rem range for yields of 100 and 1000 kt. Slant range for ionizing and thermal radiation was considered a fair approximation of the ground range. (Data are from *Effects of Nuclear Weapons.*[24])

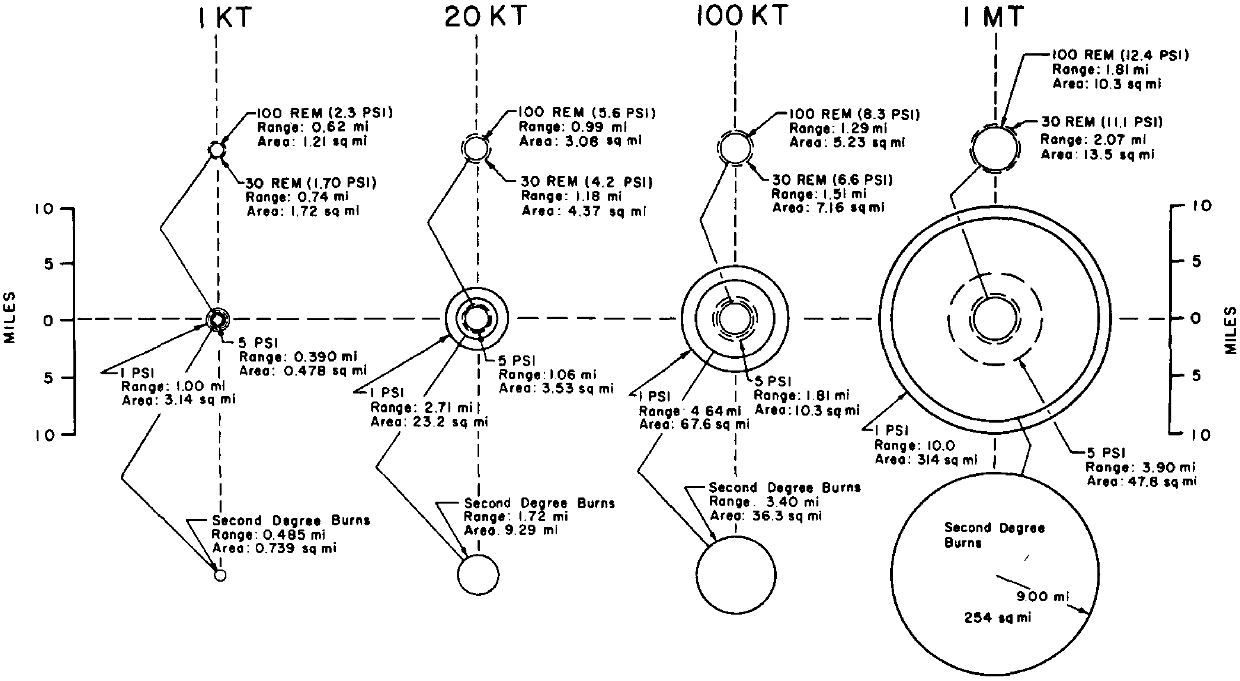


FIGURE 5: ENVIRONMENTAL VARIATIONS DUE TO BLAST, THERMAL RADIATION, AND INITIAL IONIZING RADIATION FOR 1- AND 10-MT EXPLOSIVE YIELDS

A comparison of the radii and ranges for 1- and 5-psi blast overpressure, 30 and 100 rem of initial radiation, and second-degree burns is shown to the same scale for typical air bursts of 1- and 10-Mt yields. Slant ranges for ionizing and thermal radiation was assumed to be a reasonable approximation of the ground range. (Data are from *Effects of Nuclear Weapons.*[24])

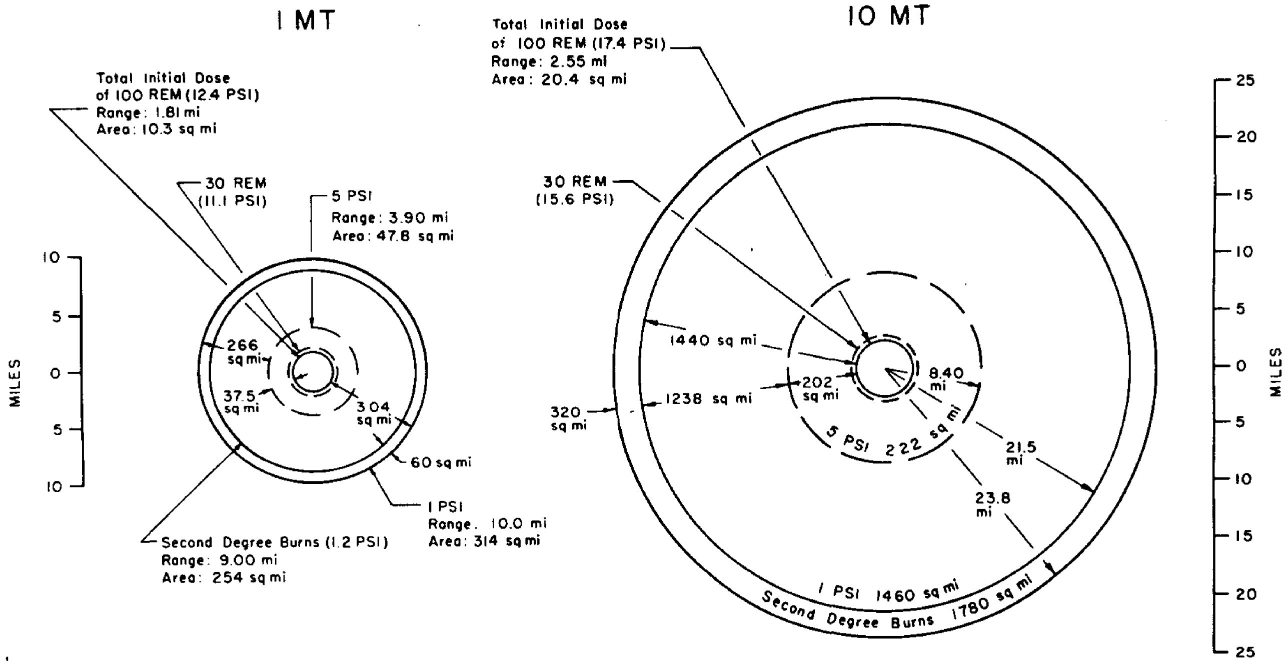


FIGURE 6: ENVIRONMENTAL VARIATIONS DUE TO BLAST, THERMAL RADIATION, AND INITIAL IONIZING RADIATION FOR A 20-MT EXPLOSIVE YIELD

A comparison of the indicated effect parameters is shown for the 20-Mt typical air burst drawn to the same scale as in Fig. 5. It was assumed that the slant ranges for thermal and ionizing radiation were reasonable approximations of the ground ranges.

It is instructive to contemplate Fig. 6 from the point of view of human hazard. Exposure to 100 rem of initial radiation would cause no incapacitation. However, casualties from thermal and blast would be very high at the 100-rem location, about 3 miles from GZ, where the overpressure and thermal flux would be close to 19 psi and over 1000 cal/cm^2, respectively. Indeed, casualties from blast, flash burns, and fire would be heavy out to the 5-psi location, where houses would be completely destroyed by blast (see Table 2). Still further out, injuries would lessen and be minimal owing to blast at the 1-psi line where wooden-frame houses suffer 50 per cent damage. Serious flash and fire hazards for unprotected persons would exist out to, and even beyond, the second-degree burn line. One reason for this is the fact that thermal fluxes required to ignite fine kindling fuels are very close to those which produce second-degree burns of the bare skin. There would be no immediate fallout problem since the case under discussion involves an air burst.

(Data are from *Effects of Nuclear Weapons*.[24])

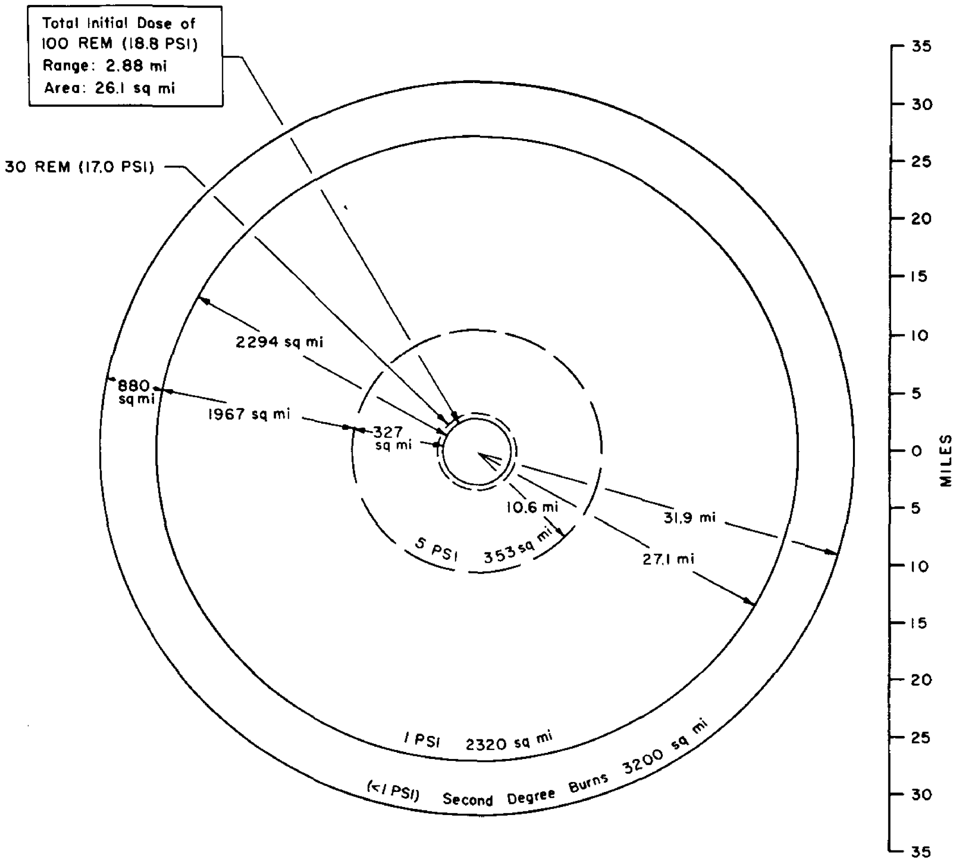


FIGURE 7: ENVIRONMENTAL VARIATIONS DUE TO BLAST, THERMAL RADIATION, AND INITIAL IONIZING RADIATION FOR A 1-KT EXPLOSIVE YIELD

Figure 7 shows an expanded plot of selected effects data for a typical air burst at a yield of 1 kt. It was assumed that slant ranges for ionizing and thermal radiation are reasonable approximations of the ground ranges. (Data are from *Effects of Nuclear Weapons*.[24])

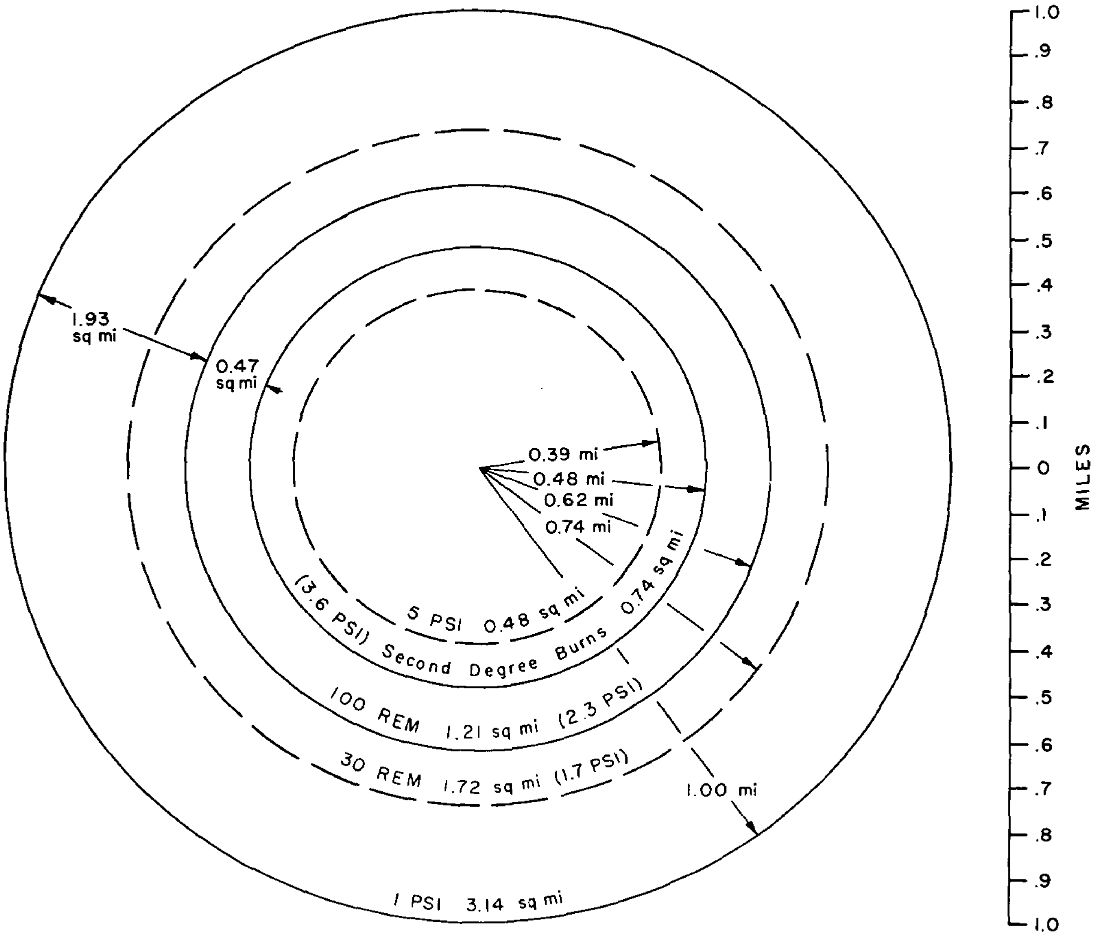


FIGURE 8: ENVIRONMENTAL VARIATIONS DUE TO BLAST, THERMAL RADIATION, AND INITIAL IONIZING RADIATION FOR A 20-KT EXPLOSIVE YIELD

Figure 8 shows an expanded plot of selected effects data for a typical air bursts at a yield of 20 kt. It was assumed that slant ranges for ionizing and thermal radiation are reasonable approximations of the ground ranges. (Data are from *Effects of Nuclear Weapons.*[24])

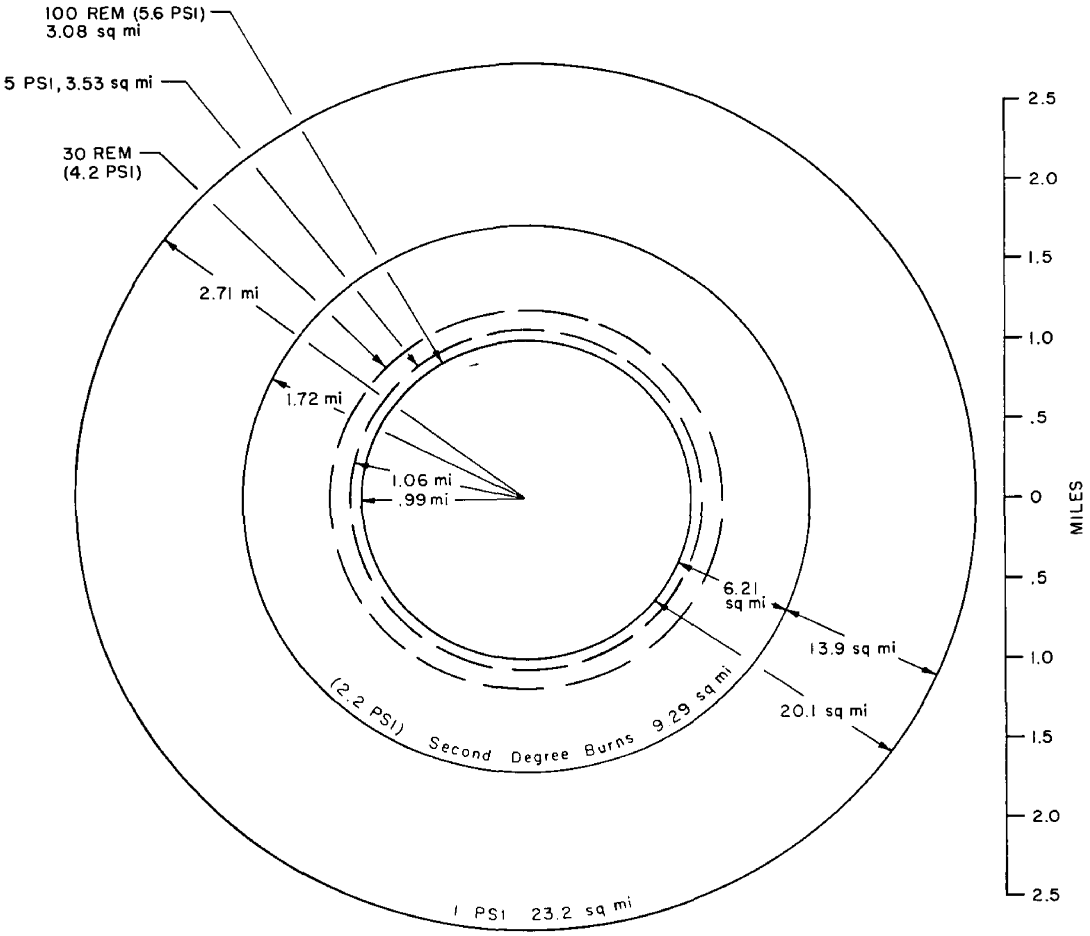


FIGURE 9: ENVIRONMENTAL VARIATIONS DUE TO BLAST, THERMAL RADIATION, AND INITIAL IONIZING RADIATION FOR A 100-KT EXPLOSIVE YIELD

Figure 9 shows an expanded plot of selected effects data for a typical air burst at a yield of 100 kt. It was assumed that slant ranges for ionizing and thermal radiation are reasonable approximations of the ground ranges. (Data are from *Effects of Nuclear Weapons*.[24])

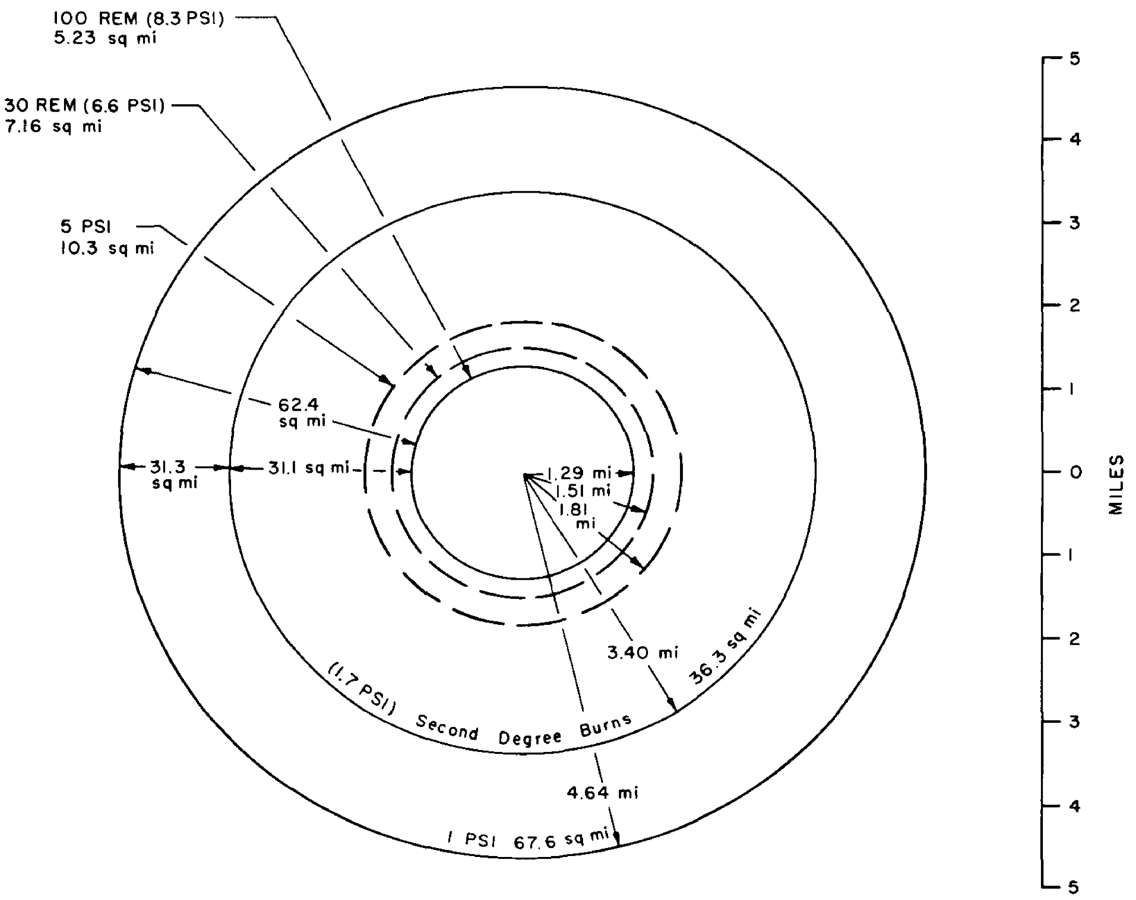


FIGURE 10: APPROXIMATE DISTANCE VS. YIELD RELATIONSHIPS FOR OVERPRESSURE, THERMAL RADIATION, AND INITIAL IONIZING RADIATION FOR A TYPICAL AIR BURST

Figure 10 summarizes graphically the yield-distance relationships for effects produced by typical air bursts and allows a comparison of the ground ranges for 30 and 100 rem of initial radiation, 1 and 5 psi, and first- and second-degree burns. It was assumed that clear weather conditions prevailed and that slant range for ionizing and thermal radiation represented a reasonable approximation of the ground range. (Data are from *Effects of Nuclear Weapons*.[24])

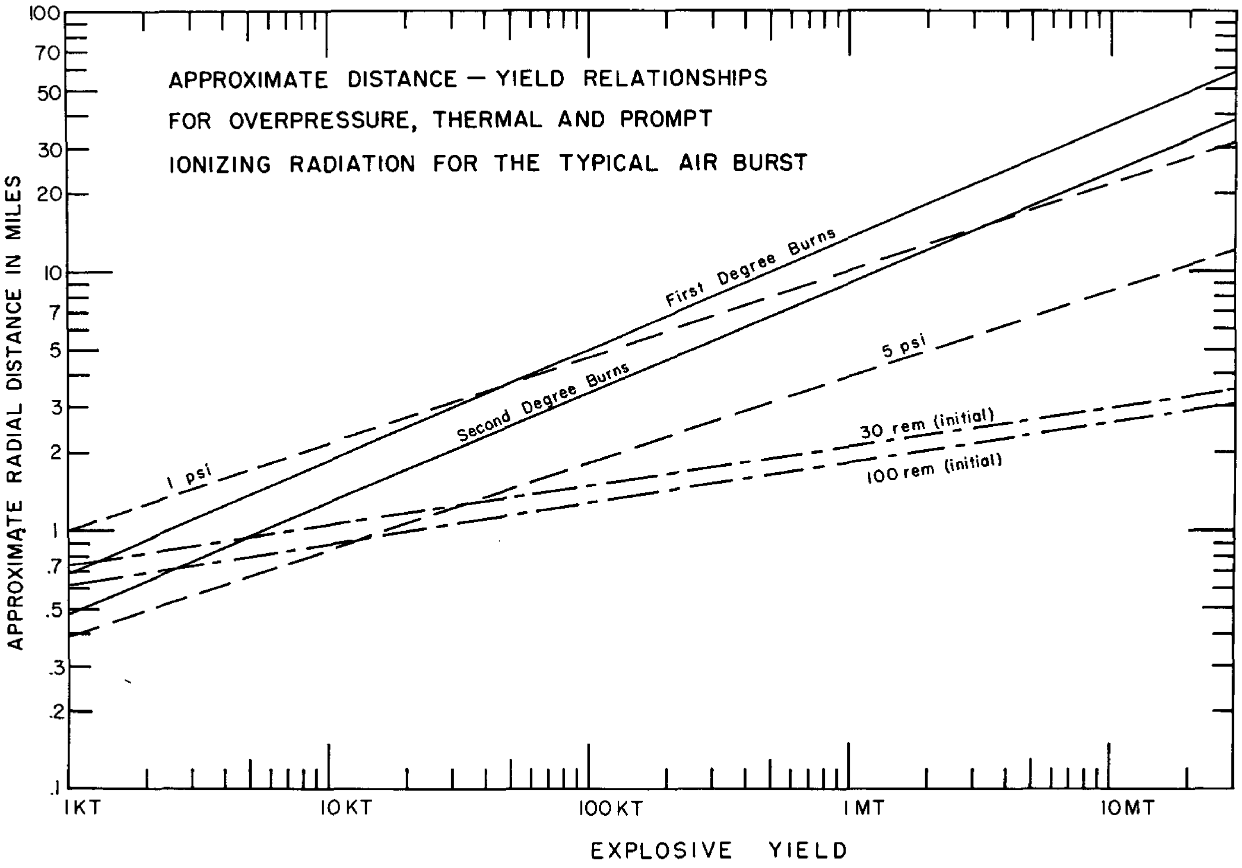


TABLE 42: COMPARATIVE EFFECTS DATA FOR A 20-MT SURFACE BURST (10 MT FISSION YIELD)

Table 42 presents approximate comparative effects data in tabular form for a surface burst of 20-Mt total yield. These data are presented graphically in Fig. 11. The presence of fallout radiation is the principle difference between this type explosion and one detonated in the air. Ranges for the 1- and 5-psi lines are somewhat shorter for the surface burst compared with the air burst.

Assumptions made in computing the fallout pattern were (1) an effective wind of 15 mph and (2) 50 per cent of the total yield was derived from fission. The latter assumption was necessary since the fusion process does not contribute significantly to the radioactivity of the fallout; i.e., the total yield determines the spatial extent of the fallout; whereas the fission yield fixes the amount and hence the level of radioactive contamination.

The somewhat hypothetical "1-hr reference dose rates" in roentgens per hour were used as a means of illustrating the relation between the fallout hazard within the immediate target area and the blast, radiation, and thermal effects. The 1-hr reference dose rate is defined as the dose rate 1 hr after the detonation, assuming that fallout were complete at that time. The somewhat artificial significance of these dose rates in terms of accumulated dose is discussed in connection with Table 43.

(Data are from *Effects of Nuclear Weapons*.[24])

	Range, miles	Area, square miles
At least first-degree burns	49.2	7600
At least second-degree burns	31.9	3200
At least third-degree burns	29.0	2640
At least 1 psi	23.5	1730
At least 5 psi	7.74	189
At least 30 rem (initial)	3.30	34.2
At least 100 rem (initial)	2.88	26.1
At least 30 r/hr fallout (1-hr reference dose rate)		1660*
At least 100 r/hr fallout (1-hr reference dose rate)		1240*
At least 300 r/hr fallout (1-hr reference dose rate)		895*
At least 1000 r/hr fallout (1-hr reference dose rate)		489*
At least 3000 r/hr fallout (1-hr reference dose rate)		183*
At least 1 psi and less than 30 r/hr		881
At least 1 psi and less than 100 r/hr		1240
At least second-degree burns and less than 1 psi		1460
At least second-degree burns and less than 30 r/hr		2110
At least second-degree burns and less than 100 r/hr		2800

*Measured only to first-degree burn line. Effective wind assumed to be 15 mph.

FIGURE 11: COMPARATIVE EFFECTS FOR A 20-MT SURFACE BURST

Figure 11 graphically presents the effects data set forth in Table 42 referable to a surface detonation of a nuclear weapon having an assumed fission yield of 10 Mt but a total yield of 20 Mt.

The somewhat hypothetical fallout contours in terms of the 1-hr reference dose rates are depicted only to the first-degree burn limit approximately 49 miles from GZ, although the fallout might actually extend several hundred miles from the target area as dictated by the winds aloft. In the illustration a 15 mph effective wind was assumed.

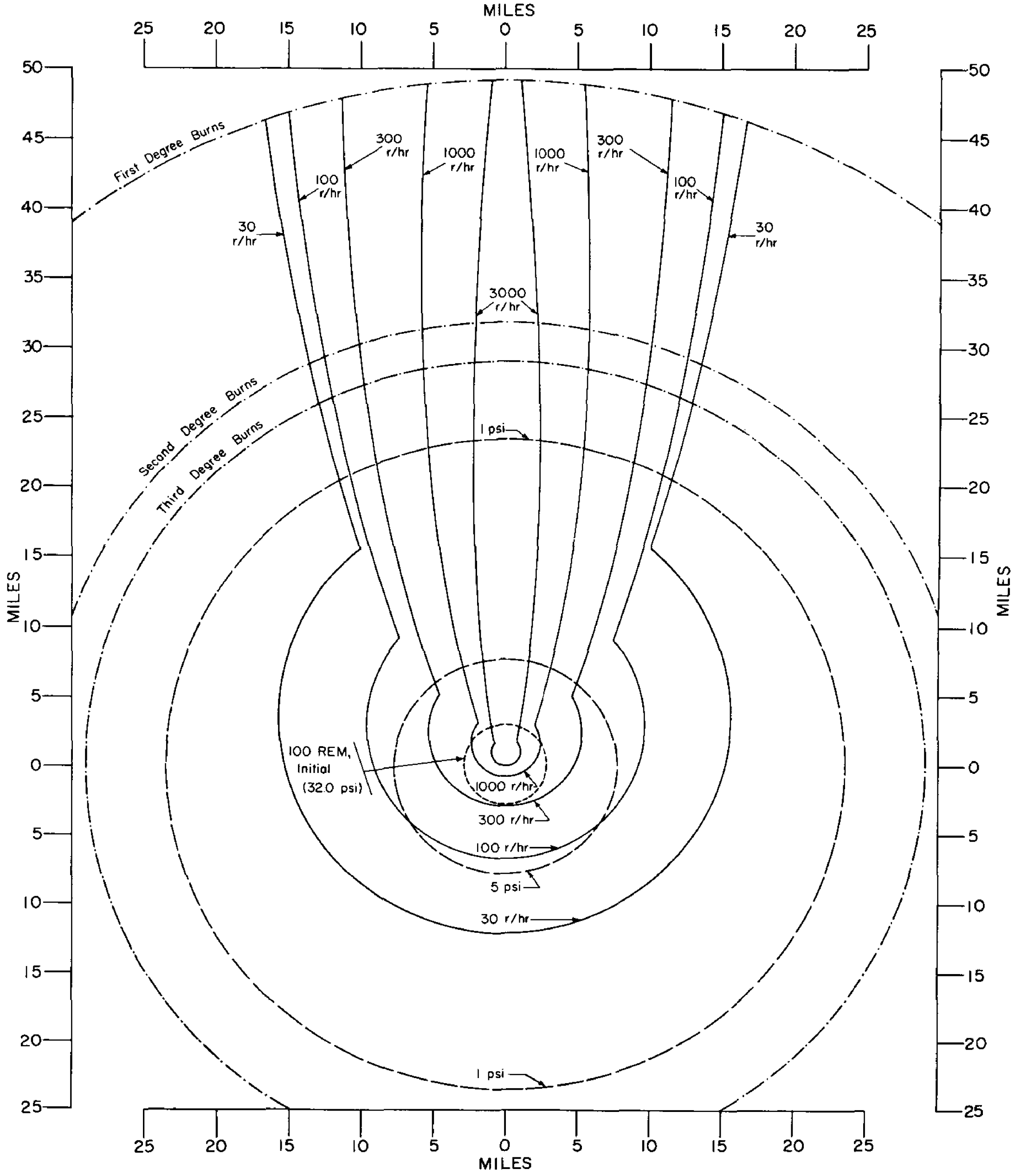


TABLE 43: ACCUMULATED RADIATION DOSE AND DOSE RATE AS A FUNCTION OF THE 1-HR REFERENCE DOSE RATE AND TIME AFTER DETONATION

Table 43 shows the exposure dose rate and accumulated dose from penetrating radiation as functions of the time after detonation and selected 1-hr reference dose rates in unprotected locations. Accumulation of radiation dose was calculated starting at 15 min after the detonation. It is well to note that if a shelter equivalent to 3 ft of earth were available, the exposure doses within the shelter would be approximately 1/1000 of the exposure doses tabulated in the body of the table. (Data are from *Effects of Nuclear Weapons*.[24])

Two examples will be given of ways Table 43 might be useful to crudely approximate accumulated dose from penetrating fallout radiations.

Example 1: Assume that an individual were exposed to fallout radiations near the 1000 r/hr 1-hr-reference isodose-rate line shown in Fig. 11. This person, if unprotected, would have accumulated approximately 1600 r at the end of the first hour after detonation (see table). Such a value assumes that the fallout was complete at this location in question within 15 min after the burst. At the end of 1 hr after the explosion, the dose rate would be 1000 r/hr. At the end of the second hour, Table 43 shows that the exposure dose rate would have dropped to near 435 r/hr and the total accumulated dose would be 2250 r. If, on the other hand, the fallout was not complete until 1 hr after detonation, then the total accumulated dose would be near 650 r, shown in parentheses in Table 43, which gives the difference between the accumulated doses shown for 1 hr (1600 r) and 2 hr (2250 r). Of course, such exposures would be fatal, but, if a fallout shelter giving radiation attenuation of 1 in 1000 (3 ft of earth) were available and used, the accumulated doses would have been 1.6, 2.25, and 0.65 r instead of 1600, 2250, and 650 r for the examples considered above.

Example 2: Assume an individual survived the burst by taking shelter, and 6 hr after the burst he measured an exposure dose rate of 128 r/hr outside the shelter. By locating this dose rate in Table 43, the individual knows his shelter was near the 1000 r/hr 1-hr-reference dose-rate contour, but more important he notes the figure (460) in the table which tells him he would accumulate 460 r were he to leave the shelter for the next 6 hr.

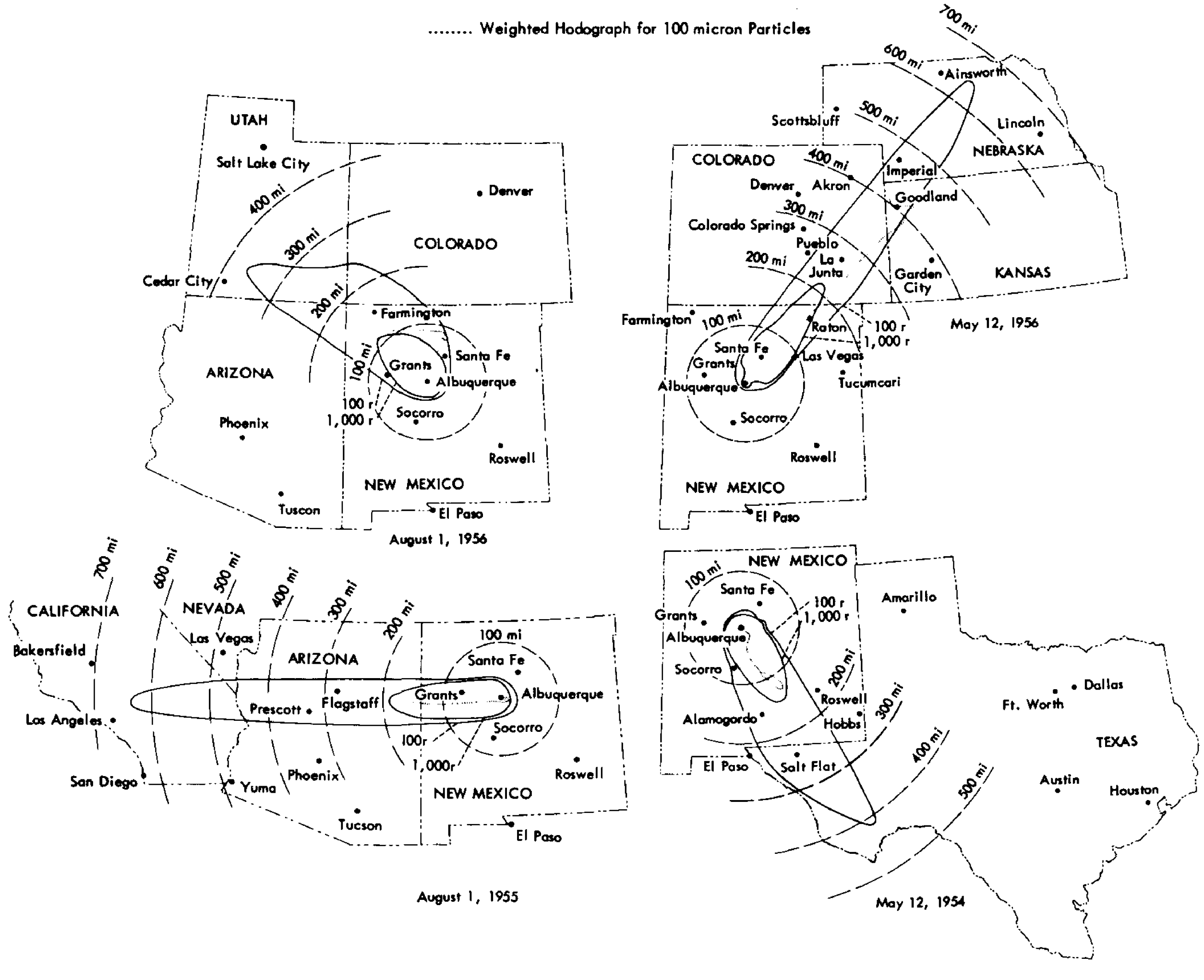
	1-hr reference dose rate*									
	30 r/hr		100 r/hr		300 r/hr		1000 r/hr		3000 r/hr	
Time after detonation*	Dose,† r	Dose rate, r/hr	Dose,† r	Dose rate, r/hr	Dose,† r	Dose rate, r/hr	Dose,† r	Dose rate, r/hr	Dose,† r	Dose rate, r/hr
1 hr	47.9	30.0	160	100	479	300	1600	1000	4790	3000
(1 hr)	(19.5)		(65)		(195)		(650)		(1950)	
2 hr	67.4	13.1	225	43.5	674	131	2250	435	6740	1310
(2 hr)	(16.8)		(56)		(168)		(560)		(1680)	
4 hr	84.2	5.68	281	19.0	842	56.8	2810	190	8420	568
(2 hr)	(8.90)		(29)		(89)		(290)		(890)	
6 hr	93.1	3.49	310	12.8	931	34.9	3100	128	9310	349
(6 hr)	(13.9)		(46)		(139)		(460)		(1390)	
12 hr	107	1.52	356	5.07	1070	15.2	3560	50.7	10700	152
(12 hr)	(11.0)		(39)		(110)		(390)		(1100)	
24 hr	118	0.662	395	2.21	1180	6.62	3950	22.1	11800	66.2
(12 hr)	(7.00)		(21)		(70)		(210)		(700)	
36 hr	125	0.407	416	1.36	1250	4.07	4160	13.6	12500	40.7
(12 hr)	(4.00		(13)		(40)		(130)		(400)	
48 hr	129	0.30	429	1.0	1290	3.0	4290	10.0	12900	30.0
(288 hr)	(22.0)		(75)		(220)		(750)		(2200)	
336 hr ~2 weeks	151	0.03	504	0.1	1510	0.3	5040	1.0	15100	3.0
(1824 hr)	(15.0)		(48)		(150)		(480)		(1500)	
2160 hr ~3 months	166	0.003	552	0.01	1660	0.03	5520	0.1	16600	0.3
(15,120 hr)	(11.0)		(37)		(110)		(370)		(1100)	
17,280 hr ~2 years	177	0.0003	589	0.001	1770	0.003	5890	0.01	17700	0.03
(112,320 hr)	(7.00)		(23)		(70)		(230)		(700)	
129,600 hr	184	0.00003	612	0.0001	1840	0.0003	6120	0.001	18400	0.003
~15 years	(14.0)		(48)		(140)		(480)		(1400)	
Infinity dose	198		660		1980		6600		19800	

*Numbers in parentheses represent differences between adjacent values.

†Doses computed starting at 15 min after detonation.

FIGURE 12: INFINITY ISODOSE CONTOURS FOR A 20-MT SURFACE BURST COMPUTED FROM WIND DATA ON FOUR SELECTED DAYS

Infinity isodose contours for penetrating fallout radiation were computed for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque for wind patterns of four selected dates. No radiation shielding was assumed. The computed center of the path of 100-μ fallout particles is shown to illustrate that winds aloft may change in velocity and direction as a function of time and hence influence the ground path of particulates falling from various altitudes. Ranges from GZ and the outline of neighboring states and cities are also presented to facilitate appreciation of the shape of areas that may be contaminated with radioactive debris. For areas included inside the isodose contours, see Table 45. Computations and data were furnished by Sandia Corporation, Albuquerque, N. Mex. See Cowan[13] and Young and Bledsoe[45] for details of the fallout model employed; see Young[46] for a variety of fallout contours similar to those which follow.



August 1, 1956

May 12, 1956

August 1, 1955

May 12, 1954

FIGURE 13: ISODOSE-RATE CONTOURS AT INDICATED TIME FOR A 20-MT SURFACE BURST PREDICTED FOR THE WIND PATTERN OF MAY 12, 1956

Isodose-rate contours for penetrating fallout radiation without shielding were computed for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque for the wind pattern of May 12, 1956, showing 100-, 1000-, and 10,000-r/hr contours at 15 min after the explosion and the 100- and 1000-r/hr contours 2 hr after the explosion. H-hour indicates zero time or the moment of the burst. H + $\frac{1}{4}$ and H + 2 hr denotes time $\frac{1}{4}$ and 2 hr after the detonation, respectively. For areas inside the contours, see Table 44. Computations and data were supplied by Sandia Corporation, Albuquerque, N. Mex.

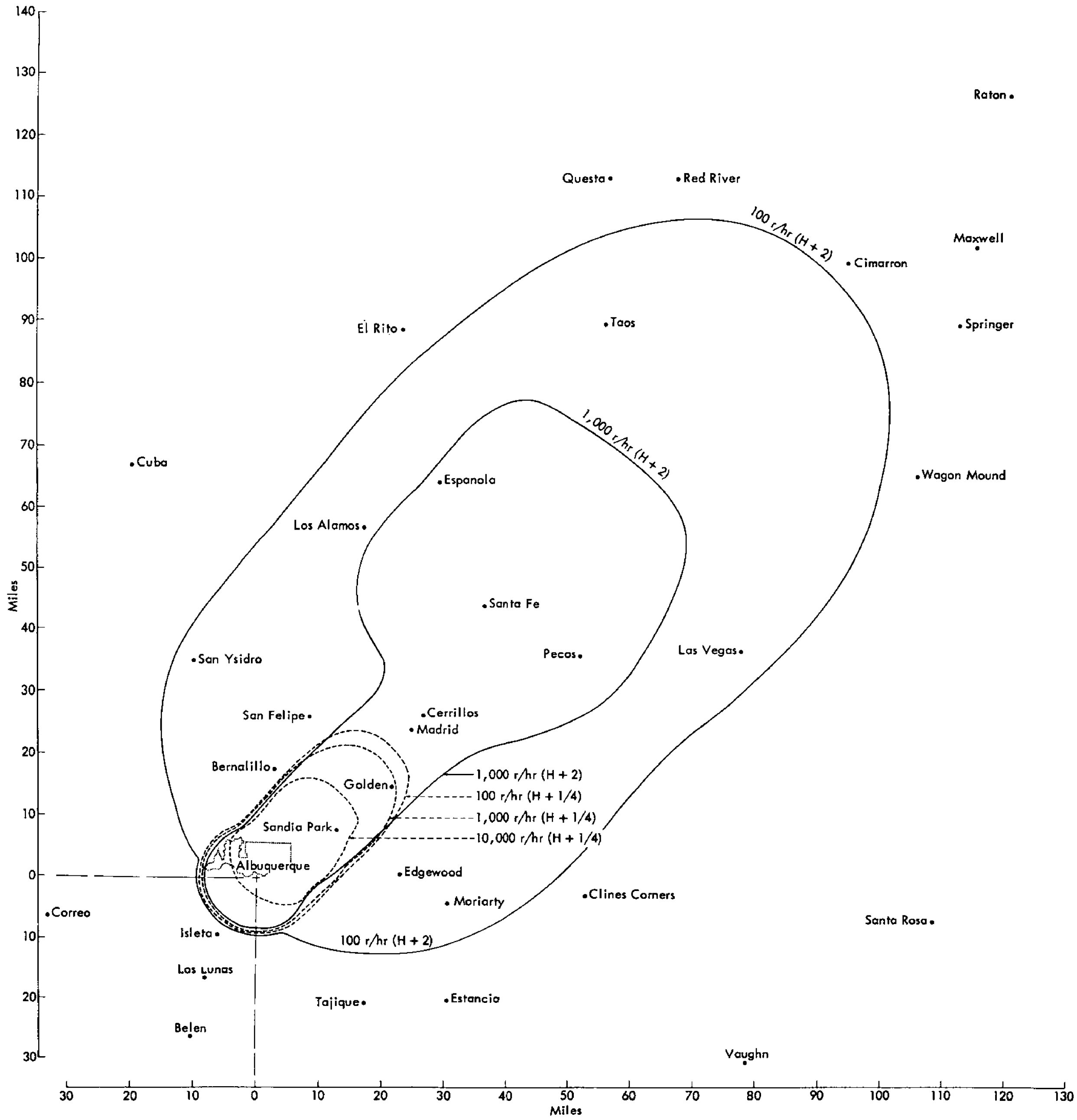


FIGURE 14: ISODOSE CONTOURS FOR A 20-MT SURFACE BURST PREDICTED FOR THE WIND PATTERN OF MAY 12, 1956

Isodose contours were computed for penetrating fallout radiation without protection or shielding for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque for the wind pattern of May 12, 1956, showing the regions inside which the accumulated exposure dose would be 100, 400, 1000, 4000, r or more at H + 1 and H + 2 hr; i.e., 1 and 2 hr after the detonation. Note the "embryonic" hot spot enclosed by the 4000-r isodose contours. See Table 45 for areas enclosed within the several labelled portions of the chart. Computations and data were supplied by Sandia Corporation, Albuquerque, N. Mex.

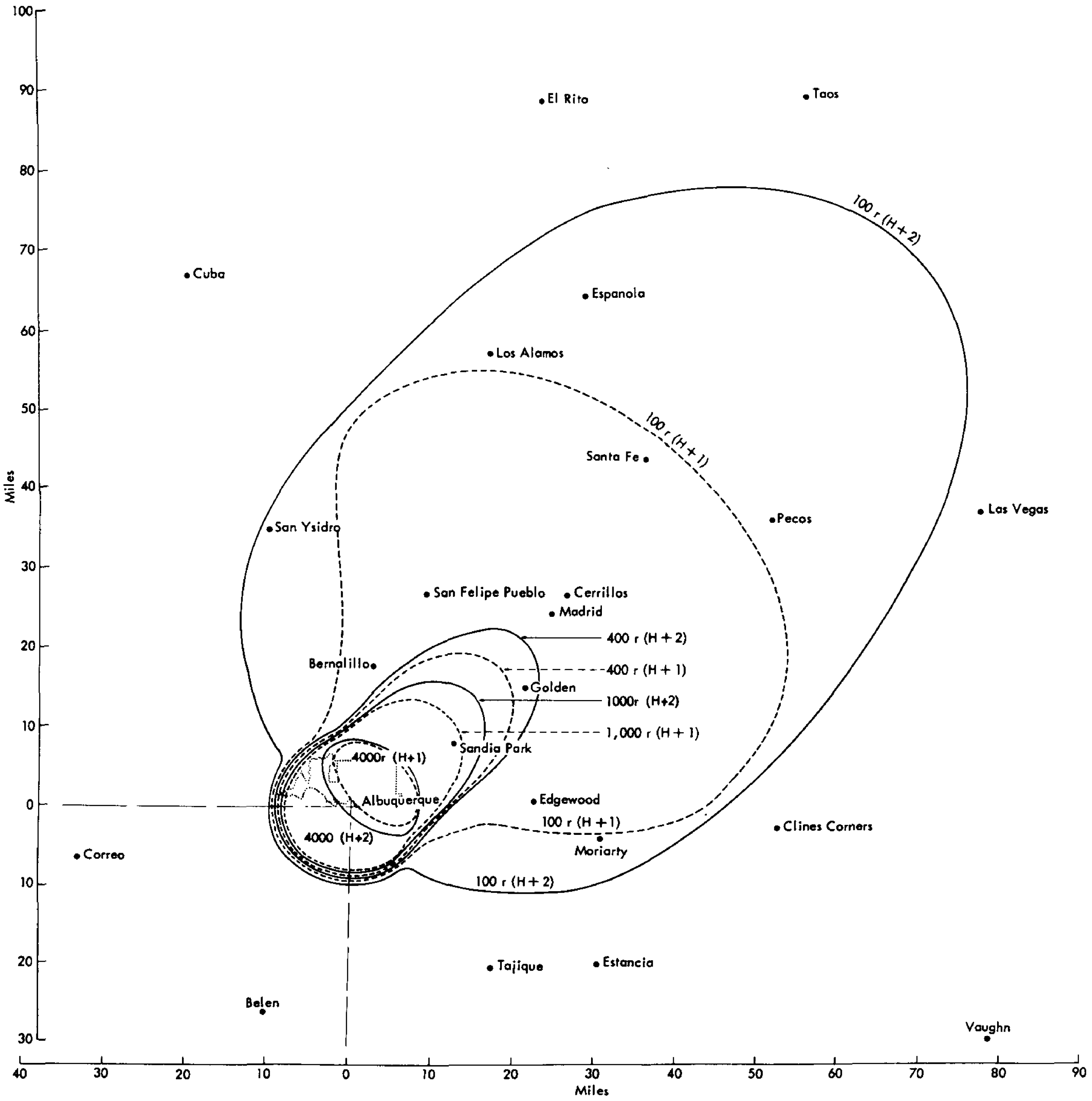


FIGURE 15: INFINITY ISODOSE CONTOURS FOR A 20-MT SURFACE BURST PREDICTED FOR THE WIND PATTERN OF MAY 12, 1956

Infinity isodose contours for penetrating fallout radiation at "near" ranges for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque were computed using the wind pattern of May 12, 1956, and assuming no shielding or countermeasures to minimize radiation exposure. Note the 8000-r hot spot near the northeast corner of the city. Computations and data were supplied by Sandia Corporation, Albuquerque, N. Mex.

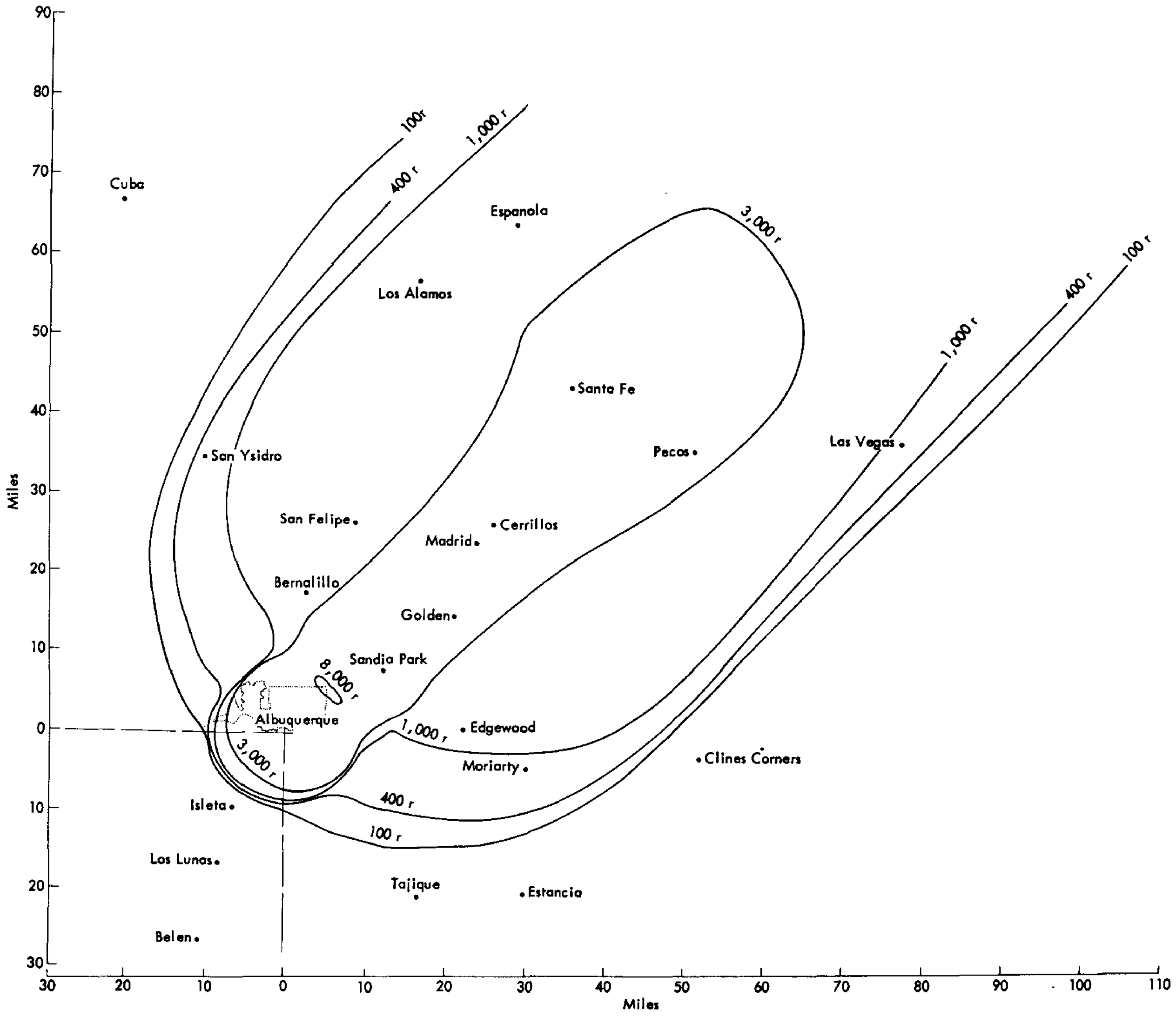


FIGURE 16: ISODOSE-RATE CONTOURS AT INDICATED TIMES FOR A 20-MT SURFACE BURST PREDICTED FOR THE WIND PATTERN OF AUG. 1, 1956

Isodose-rate contours for penetrating fallout radiation (unshielded) were computed for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque for the wind pattern of Aug. 1, 1956, showing the 100-, 1000-, and 20,000-r/hr contours for H + $^1/_4$ hr, and the 100- and 1000-r/hr contours at H + 2 hr. Note the difference in shape of the $^1/_4$-hr compared with the 2-hr contours and the similarity to the isodose contours in Fig. 17, where remarks relevant to the wind pattern are set forth. Computations and data were supplied by Sandia Corporation, Albuquerque, N. Mex.

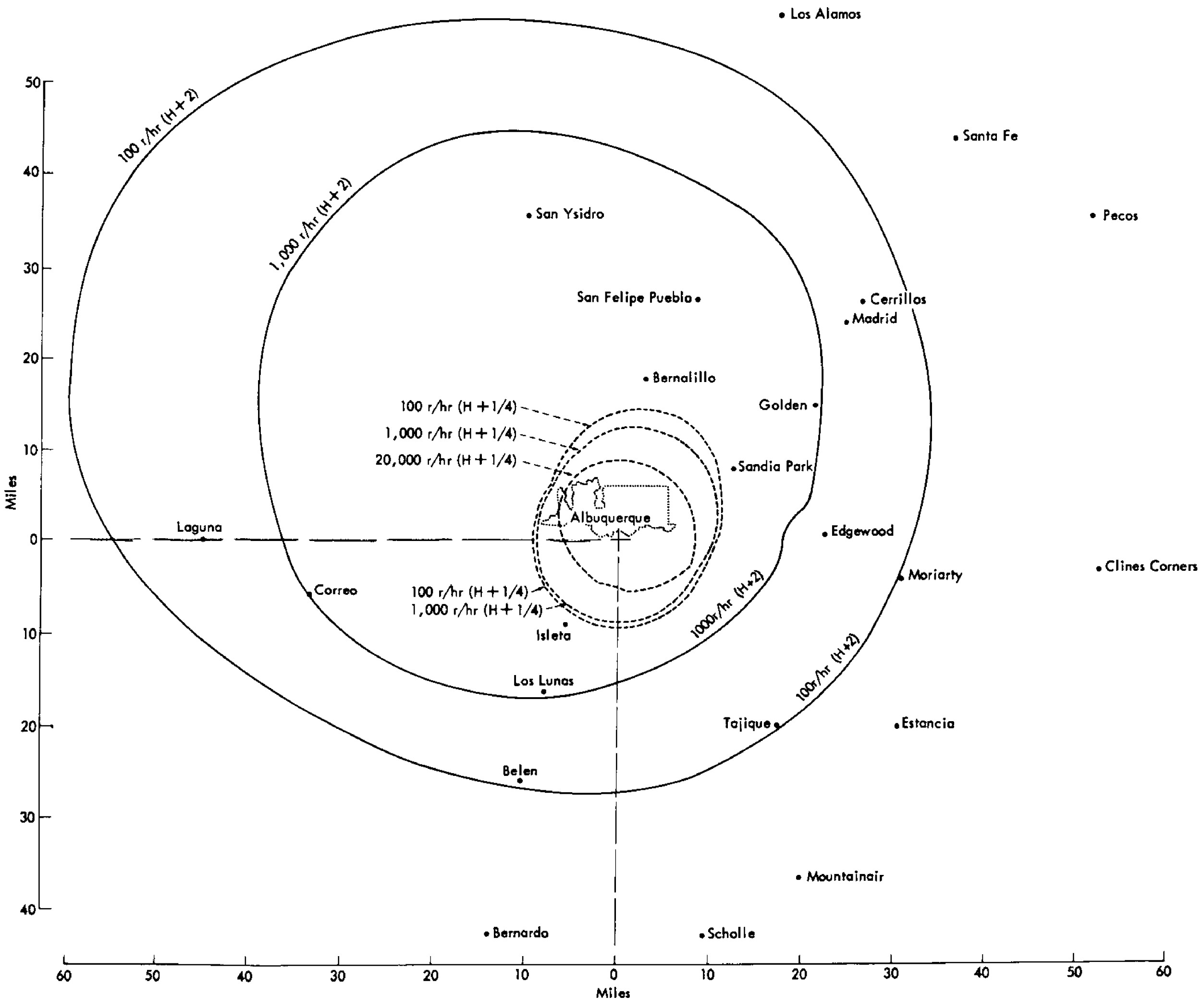


FIGURE 17: ISODOSE CONTOURS FOR A 20-MT SURFACE BURST PREDICTED FOR THE WIND PATTERN OF AUG. 1, 1956

Isodose contours were computed for penetrating fallout radiation without shielding for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque for the wind pattern of Aug. 1, 1956, showing the regions inside which the accumulated exposure dose would have been 100, 400, 1000, and 5000 r or more at H + 1 and H + 2 hr. Note the drift of the higher dose contours toward the north and slightly east; whereas the lower dose contours are more symmetrical and are generally centered to the northwest. Such behavior of fallout reflects the fact that the lower altitude winds are blowing toward the north and east, and those at higher altitudes are moving to the northwest, facts which are reflected by the computed ground path of the 100-μ particle shown in the hodograph for Aug. 1, 1956, in Fig. 12. Computations and data were supplied by Sandia Corporation, Albuquerque, N. Mex.

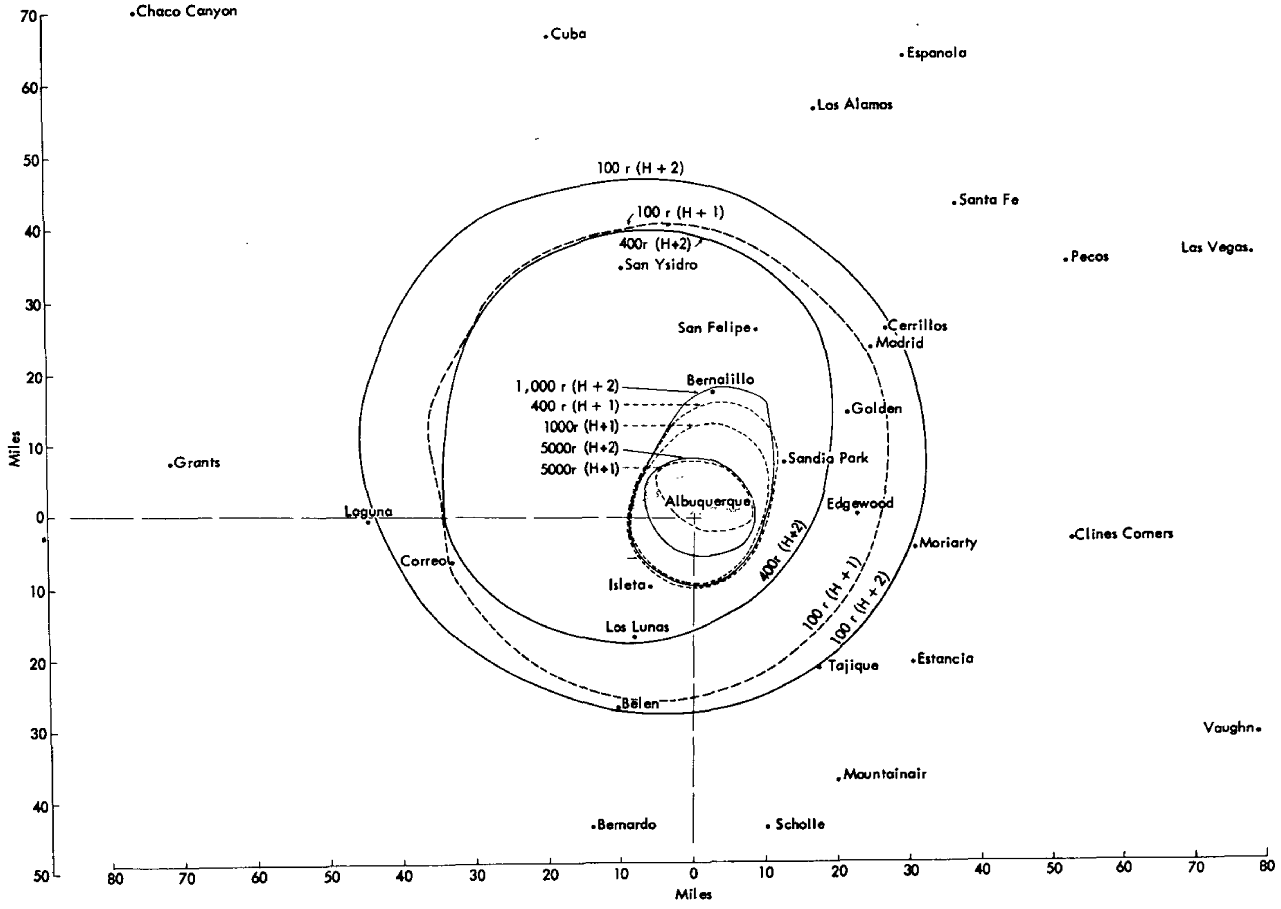


TABLE 44: AREAS (IN SQUARE MILES) ENCLOSED WITHIN SPECIFIED ISODOSE-RATE CONTOURS COMPUTED FOR PENETRATING FALLOUT RADIATION AND UNSHIELDED CONDITIONS FROM A 20-MT SURFACE BURST (10 MT FISSION YIELD) AT ALBUQUERQUE USING WIND PATTERNS OF INDICATED DATES

Computed and assembled from data supplied by Sandia Corporation, Albuquerque, N. Mex.

Time after burst	Date of winds	Areas for specified isodose-rate contours, square miles							
		100 r/hr	200 r/hr	400 r/hr	700 r/hr	1000 r/hr	4000 r/hr	10,000 r/hr	20,000 r/hr
15 min	8-1-55	400	390	370	360	350	310	290	270
	5-12-56	640	610	600	580	570	370	280	230
	8-1-56	390	370	360	340	330	280	260	170
	5-12-54					Not computed			
2 hr	8-1-55				6400	3000	320	110	
	5-12-56	9000	7800	6300	4000	2800	580	200	90
	8-1-56	6300	5100	4100	3400	3100	360	230	150
	5-12-54					Not computed			

TABLE 45: AREAS (IN SQUARE MILES) INCLUDED WITHIN SPECIFIED ISODOSE CONTOURS COMPUTED FOR PENETRATING FALLOUT RADIATION AND UNSHIELDED CONDITIONS FROM A 20-MT SURFACE BURST (10 MT FISSION YIELD) AT ALBUQUERQUE USING WIND PATTERNS OF INDICATED DATES

Computed and assembled from data supplied by Sandia Corporation, Albuquerque, N. Mex.

Time after burst	Date of winds	Areas for specified isodose contours, square miles							
		100 r	200 r	400 r	700 r	1000 r	4000 r	10,000 r	20,000 r
1 hr	8-1-55	3,300	1,200	450	390	350	250	200	
	5-12-56	2,900	1,100	510	360	330	300	170	
	8-1-56	3,400	730	410	380	320	240	220	66
	5-12-54				Not computed				
2 hr	8-1-55	4,800	3,400	2,400	880	470	290	210	
	5-12-56	5,800	1,500	600	430	410	330	170	
	8-1-56	4,600	4,100	2,500	730	420	260	230	120
	5-12-54				Not computed				
Infinite	8-1-55	36,000	28,000	21,000	15,000	12,000	1,500	330	160
	5-12-56	52,000	36,000	22,000	13,000	9,500	580	230	
	8-1-56	44,000	26,000	16,000	12,000	8,900	3,500	355	170
	5-12-54	39,000	24,000	16,000	12,000	9,200	2,700	450	180

TABLE 46: COMPUTED AREAS FOR PENETRATING FALLOUT RADIATION INSIDE INDICATED ISODOSE CONTOURS AT SPECIFIED TIMES AFTER DETONATION FOR VARIOUS EXPLOSIVE YIELDS

A 15-mph wind was assumed at all altitudes and 100 and 50 per cent fission yields were assumed for kiloton and megaton yields, respectively. (Data are from *Effects of Nuclear Weapons.*[24])

Time after burst	Total explosive yield	Areas for specified isodose contours, square miles			
		100 r	300 r	1000 r	3000 r
1 hr	1 kt	2.0	0.72	0.20	0.041
	20 kt	19	9.3	3.6	1.1
	100 kt	62	34	16	6.6
	1 Mt	340	230	150	82
	10 Mt	1,300	1,000	800	580
	20 Mt	1,900	1,500	1,200	920
2 hr	1 kt	2.7	1.0	0.28	0.063
	20 kt	29	13	5.0	1.6
	100 kt	98	52	23	9.2
	1 Mt	600	370	210	110
	10 Mt	2,400	1,700	1,200	760
	20 Mt	3,500	2,400	1,700	1,200
24 hr	1 kt	5.6	2.2	0.63	0.16
	20 kt	74	32	11	3.6
	100 kt	310	150	52	20
	1 Mt	2,300	1,100	500	210
	10 Mt	12,000	6,200	3,200	1,500
	20 Mt	16,000	9,400	4,900	2,600
1 week	1 kt	7.1	2.8	0.82	0.22
	20 kt	110	44	15	4.8
	100 kt	460	220	72	26
	1 Mt	3,700	1,600	700	270
	10 Mt	23,000	11,000	5,000	2,100
	20 Mt	32,000	16,000	8,000	3,800
1 month	1 kt	7.8	3.0	0.88	0.25
	20 kt	120	48	16	5.4
	100 kt	520	240	80	28
	1 Mt	4,400	1,900	800	300
	10 Mt	29,000	13,000	5,900	2,400
	20 Mt	44,000	21,000	10,000	4,400
Infinite	1 kt	8.4	3.2	0.93	0.26
	20 kt	130	52	18	5.7
	100 kt	560	260	87	30
	1 Mt	4,700	2,000	840	320
	10 Mt	32,000	14,000	6,500	2,700
	20 Mt	56,000	25,000	12,000	5,200

FIGURE 18: DIRECTION OF FALLOUT FROM A 20-MT SURFACE BURST AT ALBUQUERQUE FOR SUMMER SEASONS COMPUTED USING WIND DATA SAMPLED RANDOMLY (BI-MONTHLY OVER FIVE YEARS)

The computed ground pathways (weighted hodographs) of 100-μ fallout particles from a 20-Mt surface burst (10 Mt fission yield) at Albuquerque are presented. Such hodographs generally indicate the center of the fallout path. Although this is not always precisely true, the accuracy is sufficient to illustrate the variable nature of the winds during the summer season. Note that the lower altitude winds may move radioactive debris away from the city in one direction only to have those at higher altitudes sweep the fallout back over or near the point of burst. On the average, particles from the lower altitudes fall at the nearer ranges and those from the higher regions fall at the farther ranges from GZ. Data and computations were supplied by Sandia Corporation, Albuquerque, N. Mex.

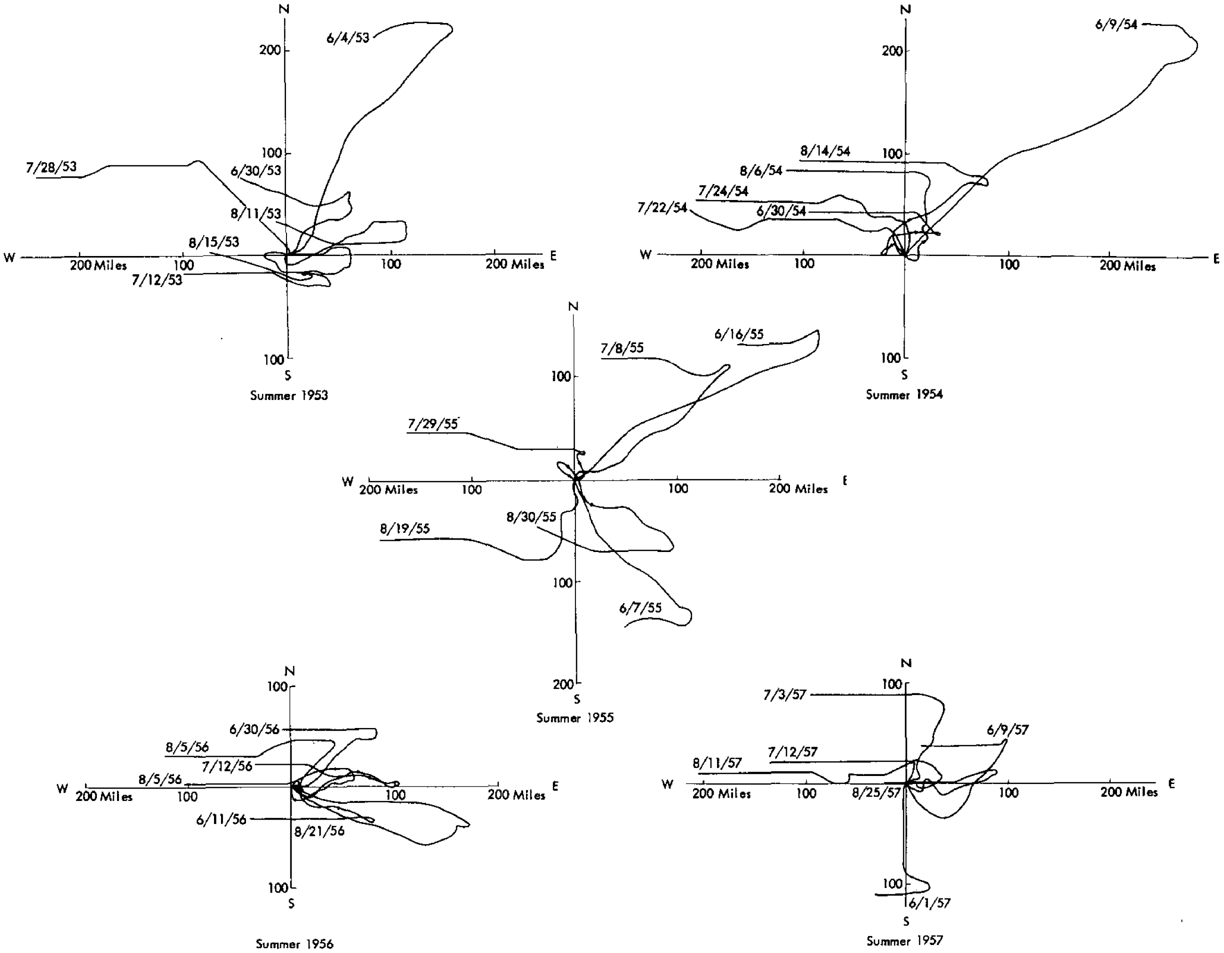


FIGURE 19: DIRECTION OF FALLOUT FROM A 20-MT SURFACE BURST AT ALBUQUERQUE COMPUTED USING WIND DATA SAMPLED RANDOMLY (BIMONTHLY OVER FIVE YEARS)

The ground paths of 100-μ fallout particles were computed for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque. Assuming the hodographs indicate the general direction of the fallout, it is clear that though the prevailing winds in the Albuquerque area are toward the east, there is no sector in and about the city and state which might not be contaminated; e.g., the winds aloft on any given day would control the fallout pattern, and from day to day are so variable as to make it imprudent to assume any sector of the state would escape fallout. Too, there is the problem of fallout from cities on the west coast and nearby states to consider. Over-all the only sound conclusion useful in planning is that all portions of the city and nearby environs are potential recipients of fallout. The corollary of this is that fallout protection is indicated for all sectors about the target area and that this is so even if warning of an imminent attack were followed by preburst evacuation. See subsequent figures for probability data. Data and computations were supplied by Sandia Corporation, Albuquerque, N. Mex.

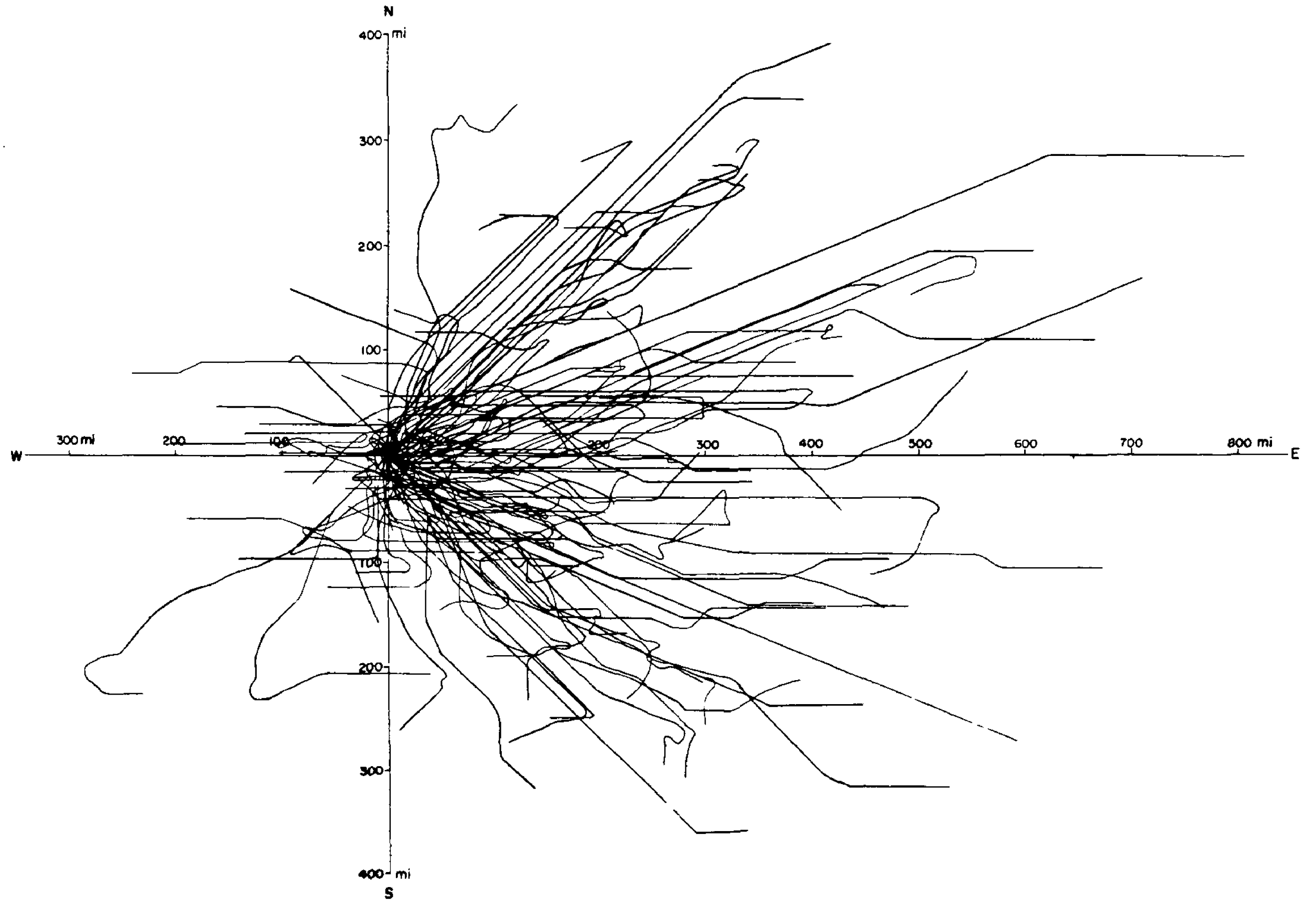


FIGURE 20: PROBABILITIES FOR FALLOUT GAMMA RADIATION FROM 1-MT BURST (SUMMER SEASON)

The probability contours inside which the infinity exposure dose from penetrating fallout radiation would be 100 r or more (unshielded) were computed for a 1-Mt surface burst ($^2/_3$ fission yield) at Albuquerque using wind data over five years for the summer seasons are presented. Compare with Fig. 21 for the winter season, and note that almost all the area of the city lies well inside the 0.5 probability line. Data and computations were supplied by Sandia Corporation, Albuquerque, N. Mex.

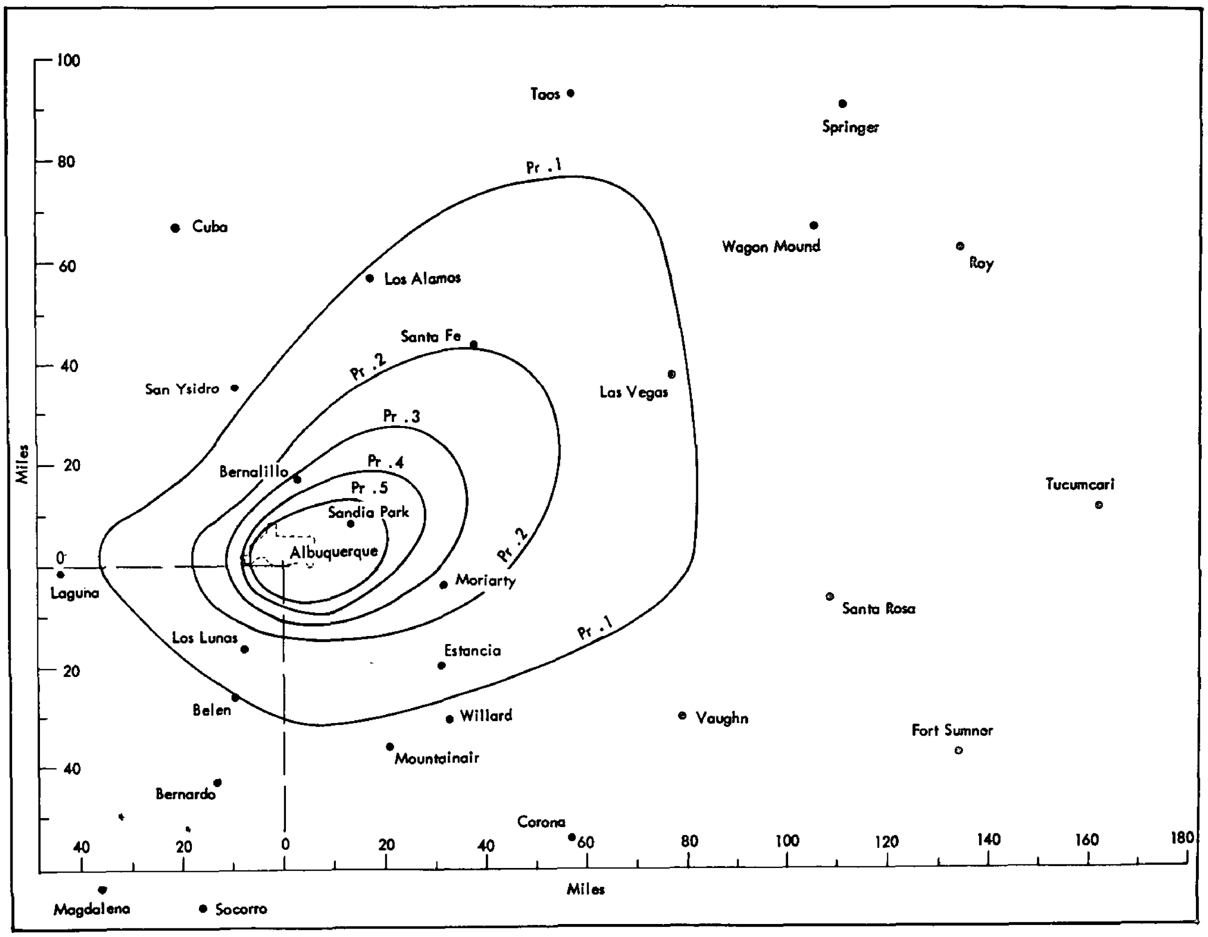


FIGURE 21: PROBABILITIES FOR FALLOUT GAMMA RADIATION FROM 1-MT BURST (WINTER SEASON)

The probability contours inside which the infinity exposure dose from penetrating fallout radiation would be 100 r or more (unshielded) were computed for a 1-Mt surface burst ($^2/_3$ fission yield) at Albuquerque using wind data over five years for the winter seasons. Compare with Fig. 20 for the summer season, and note the difference in direction of the long axis of the several probability contours. Computations and data were supplied by Sandia Corporation, Albuquerque, N. Mex.

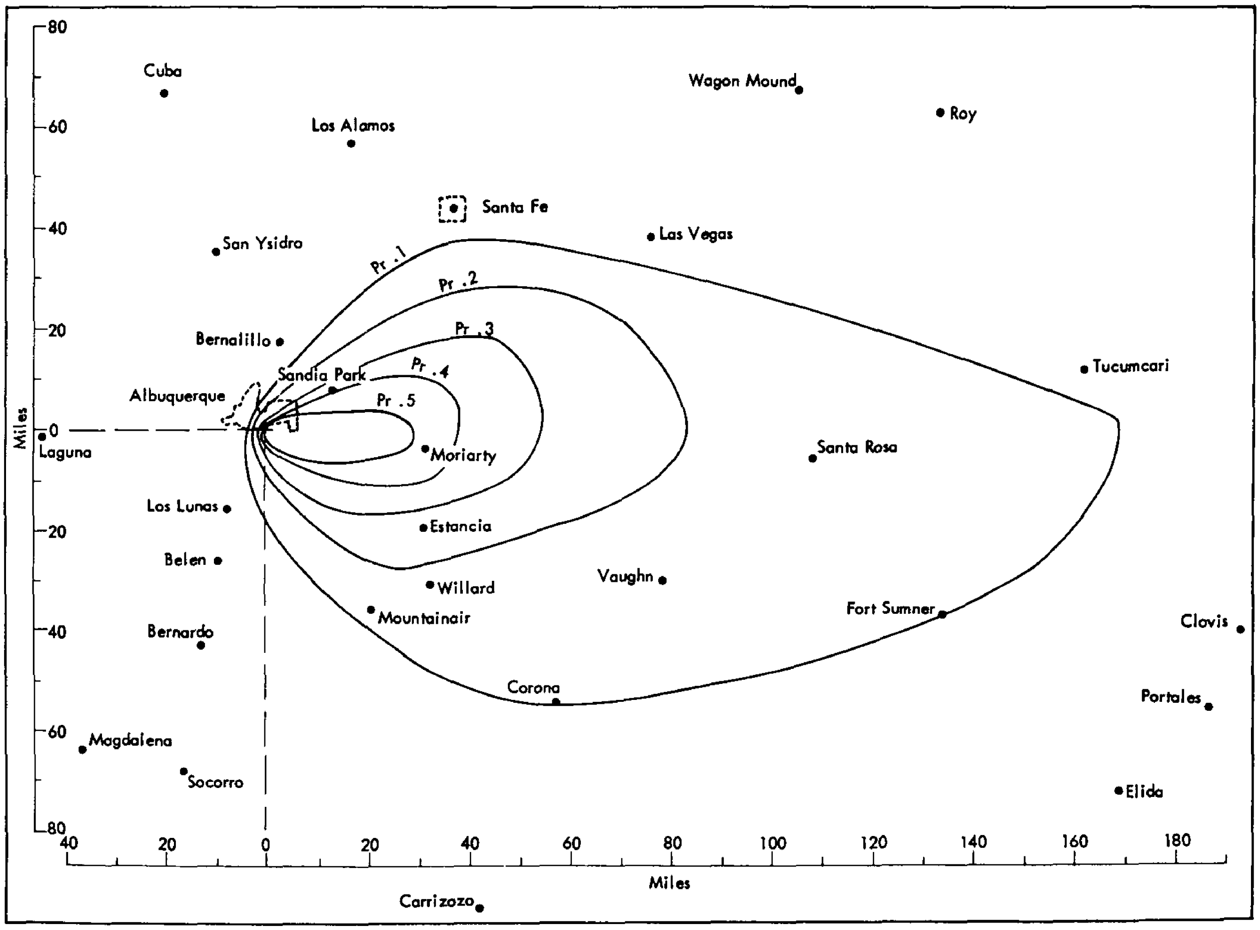


FIGURE 22: PROBABILITIES FOR FALLOUT GAMMA RADIATION FROM 20-MT BURST (SUMMER SEASON)

The probability contours inside which the infinity exposure dose from penetrating fallout radiation would be 100 r or more (unshielded) were computed for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque using wind data over five years for the summer seasons. Compare with Fig. 20 showing similar summer-season data for a 1-Mt yield, and note the shift of the long axis of the probability contours from northeast to northwest. This is so because the cloud and stem heights for the 20-Mt yield are higher than those for the 1-Mt burst and therefore fission debris is subject to transport by the winds at the higher altitudes, which, for the summer season, generally blow more to the northwest and west. Data and computations were supplied by Sandia Corporation, Albuquerque, N. Mex.

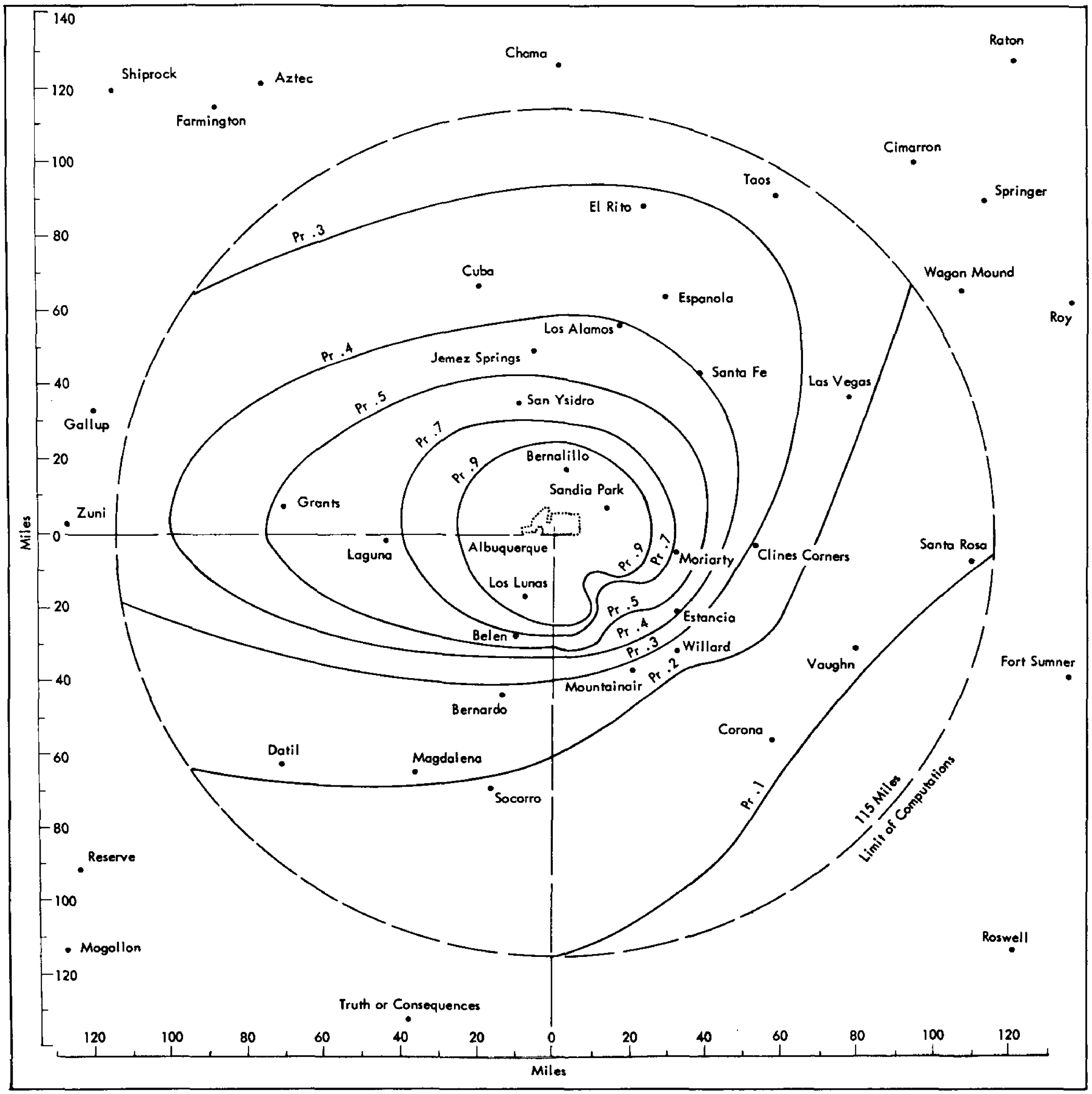


FIGURE 23: PROBABILITIES FOR FALLOUT GAMMA RADIATION FROM 20-MT BURST (WINTER SEASON)

The probability contours inside which the infinity exposure dose from penetrating fallout radiation would be 100 r or more (unshielded) were computed for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque using wind data over five years for the winter seasons. Compare with Fig. 22 for the summer seasons, and note the fallout is transported generally toward the east in winter rather than toward the northwest and west, as is the case in the summer. Data and computations were supplied by Sandia Corporation, Albuquerque, N. Mex.

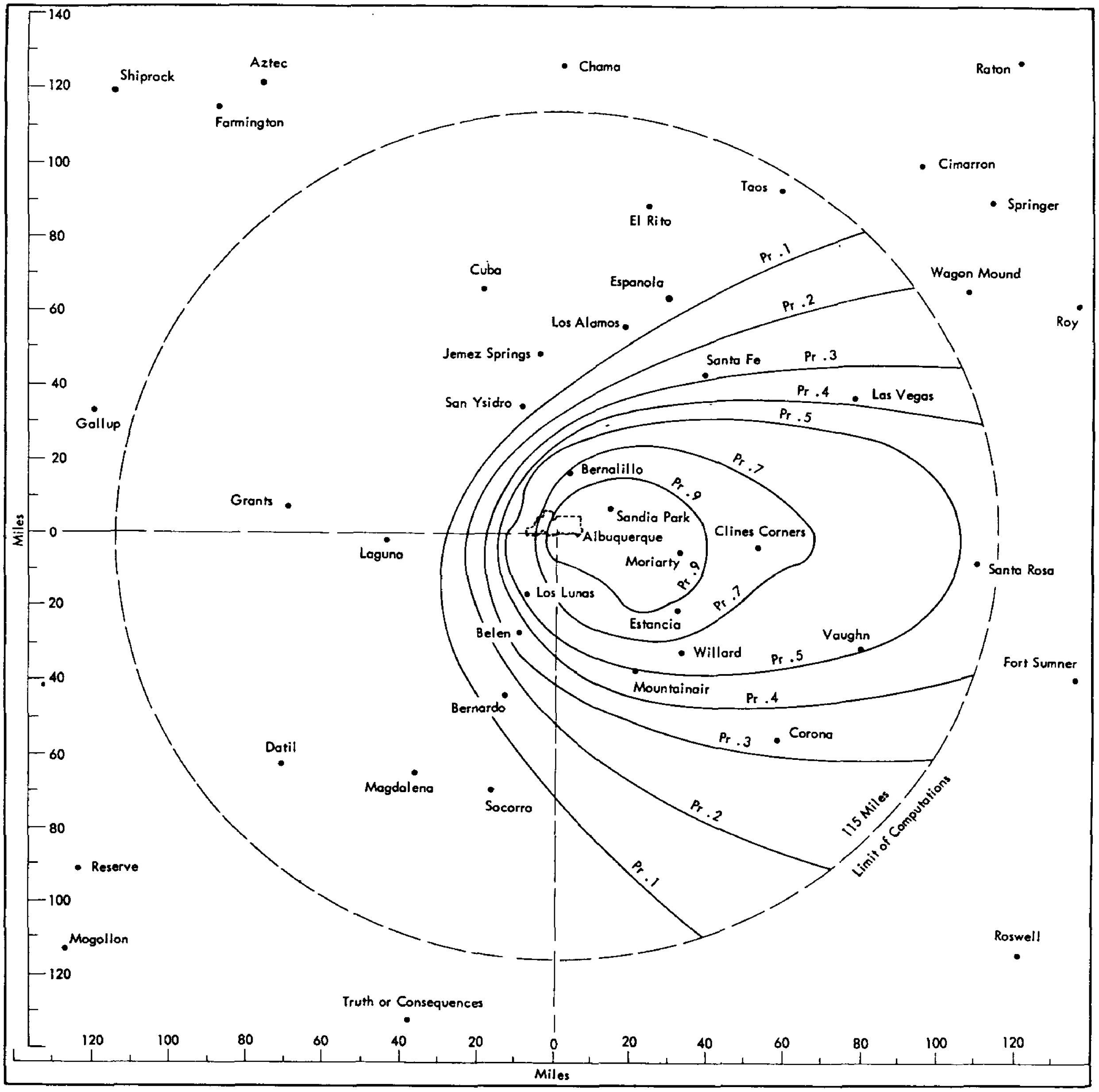


FIGURE 24: PROBABILITIES FOR FALLOUT GAMMA RADIATION FROM 20-MT BURST (SPRING SEASON)

The probability contours inside which the infinity exposure dose from penetrating fallout radiation would be 100 r or more were computed for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque using wind data over five years for the spring seasons. Note that in general the contour patterns for spring are similar to those for winter (Fig. 23) and fall (Fig. 25). Data and computations were supplied by Sandia Corporation, Albuquerque, N. Mex.

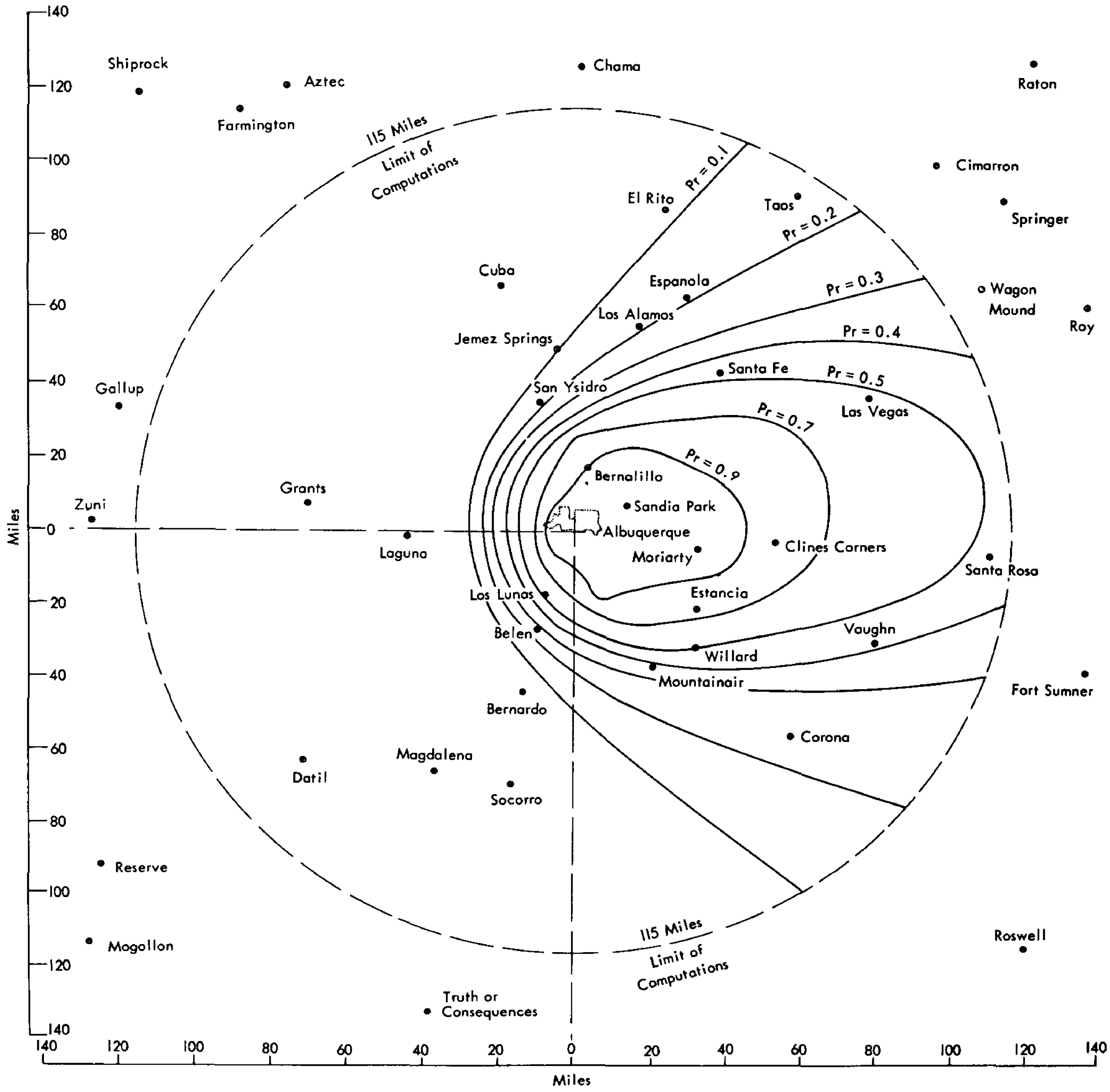


FIGURE 25: PROBABILITIES FOR FALLOUT GAMMA RADIATION FROM 20-MT BURST (FALL SEASON)

The probability contours inside which the infinity exposure dose from penetrating fallout radiation would be 100 r or more were computed for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque using wind data over five years for the fall seasons. Note that the contour patterns for fall are generally similar to those for winter (Fig. 23) and spring (Fig. 24). Data and computations were supplied by Sandia Corporation, Albuquerque, N. Mex.

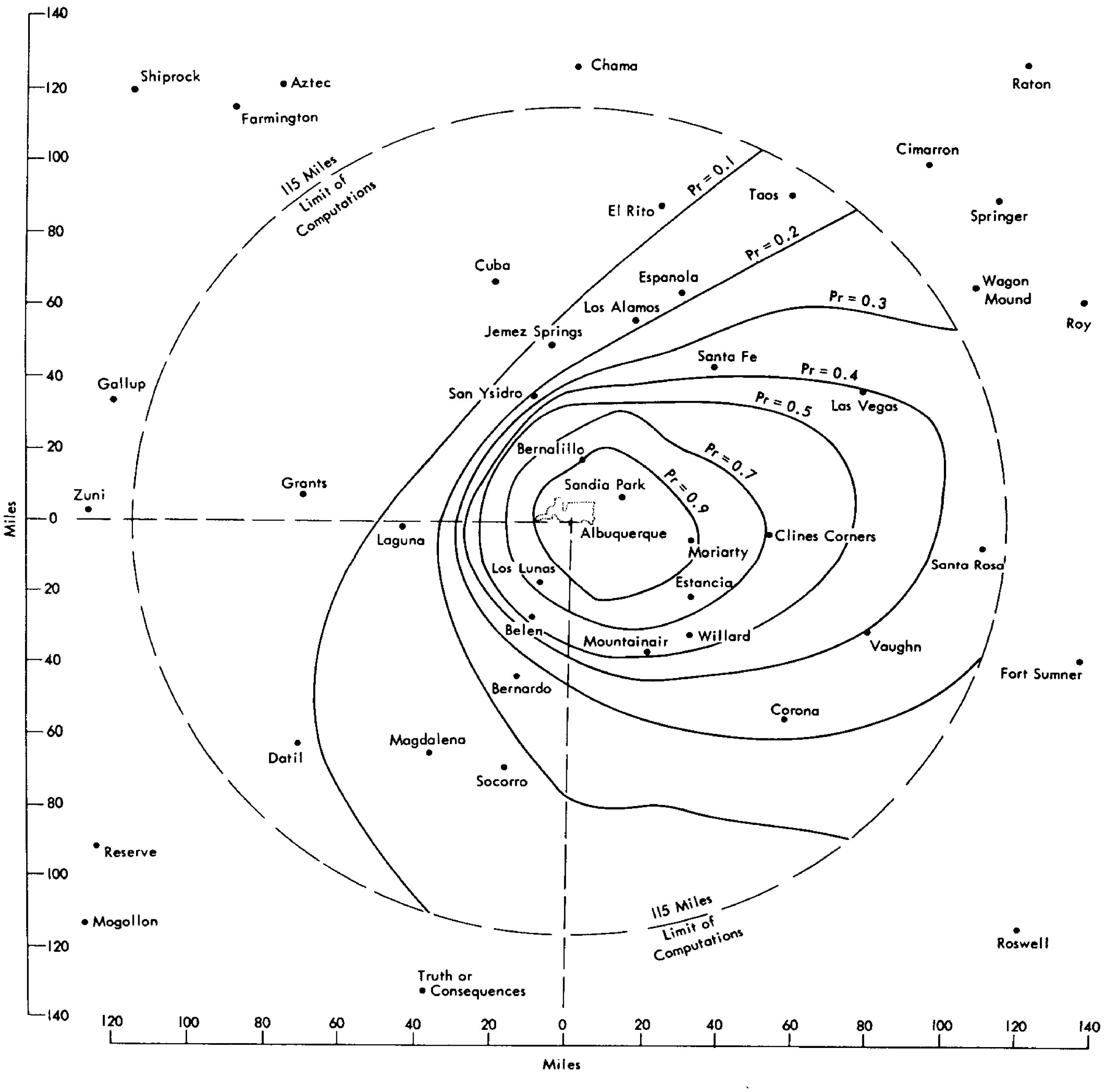


FIGURE 26: COMPUTED "MAXIMIZED" ISODOSE-RATE CONTOURS FOR 20-MT BURST

"Maximized" isodose-rate contours from penetrating fallout radiation were computed for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque using wind data over five years, showing contours for 100-, 300-, and 1000-r/hr exposure-dose rates at H + 2 hr and 100-, 300-, 1000-, 3000-, and 10,000-r/hr exposure-dose rates at H + $\frac{1}{4}$ hr. The contours define the maximal ranges at which the indicated dose rates were predicted at least one day in five years, but do not show conditions for any particular burst on any particular day, as illustrated in Figs. 12 through 17. The maximizing concept is useful for planning purposes in that it indicates from real wind data that at least once in five years a given hazard from fallout radiation reached those ranges and directions from the target set out by the several contours. Data and computations were supplied by Sandia Corporation, Albuquerque, N. Mex.

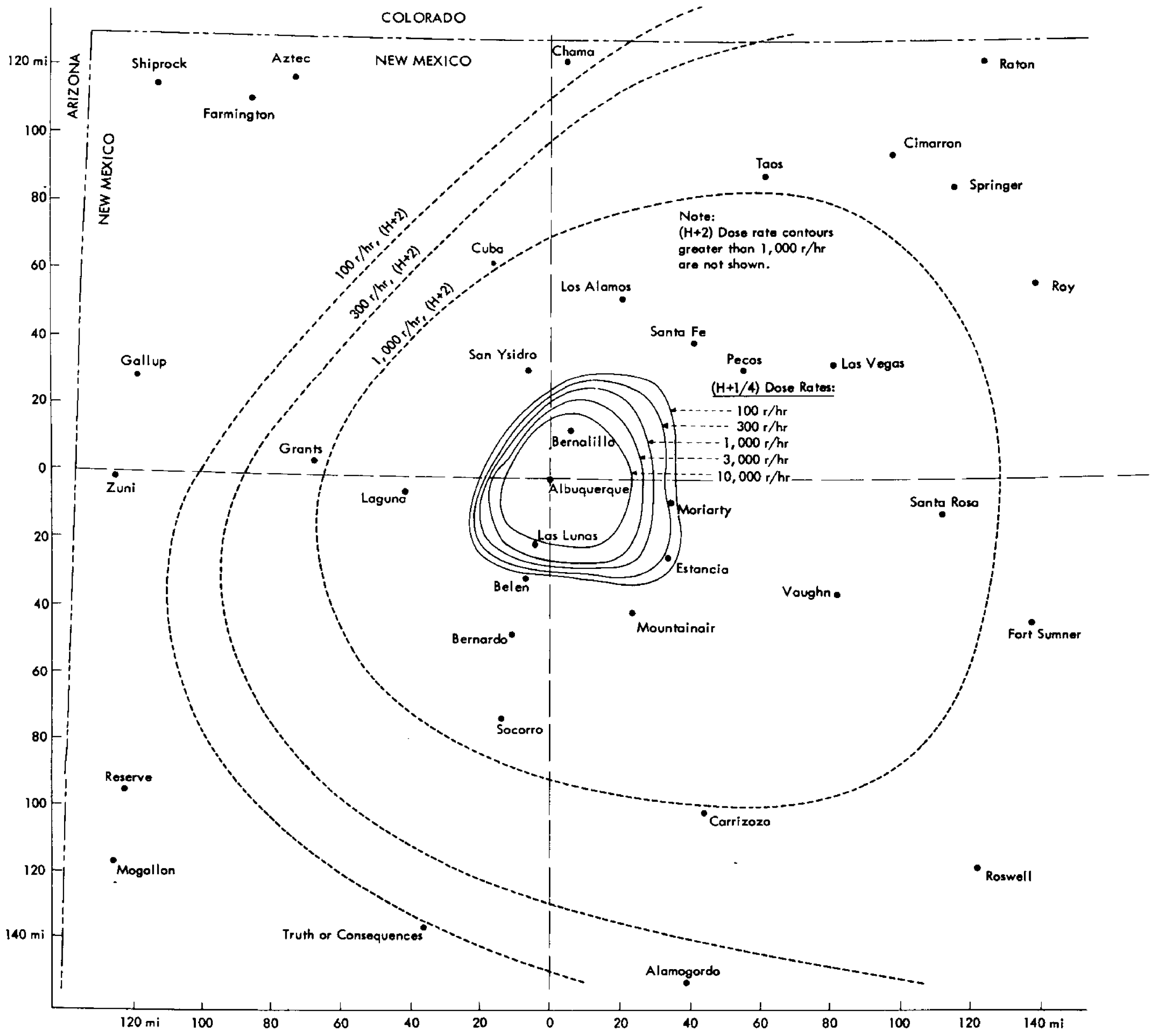


FIGURE 27: COMPUTED "MAXIMIZED" ISODOSE CONTOURS FOR 20-MT BURST

"Maximized" isodose contours from penetrating fallout radiation were computed for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque using wind data over five years showing contours for accumulated exposure doses of 100, 1000, and 10,000 r at H + 1 and H + 2 hr. The contours show the maximal ranges over a five-year period inside which the accumulated dose was the stated amount or more. As explained for Fig. 26, the "maximized" contours are not to be confused with contours computed for the wind pattern of a specified day. Computations and data were supplied by Sandia Corporation, Albuquerque, N. Mex.

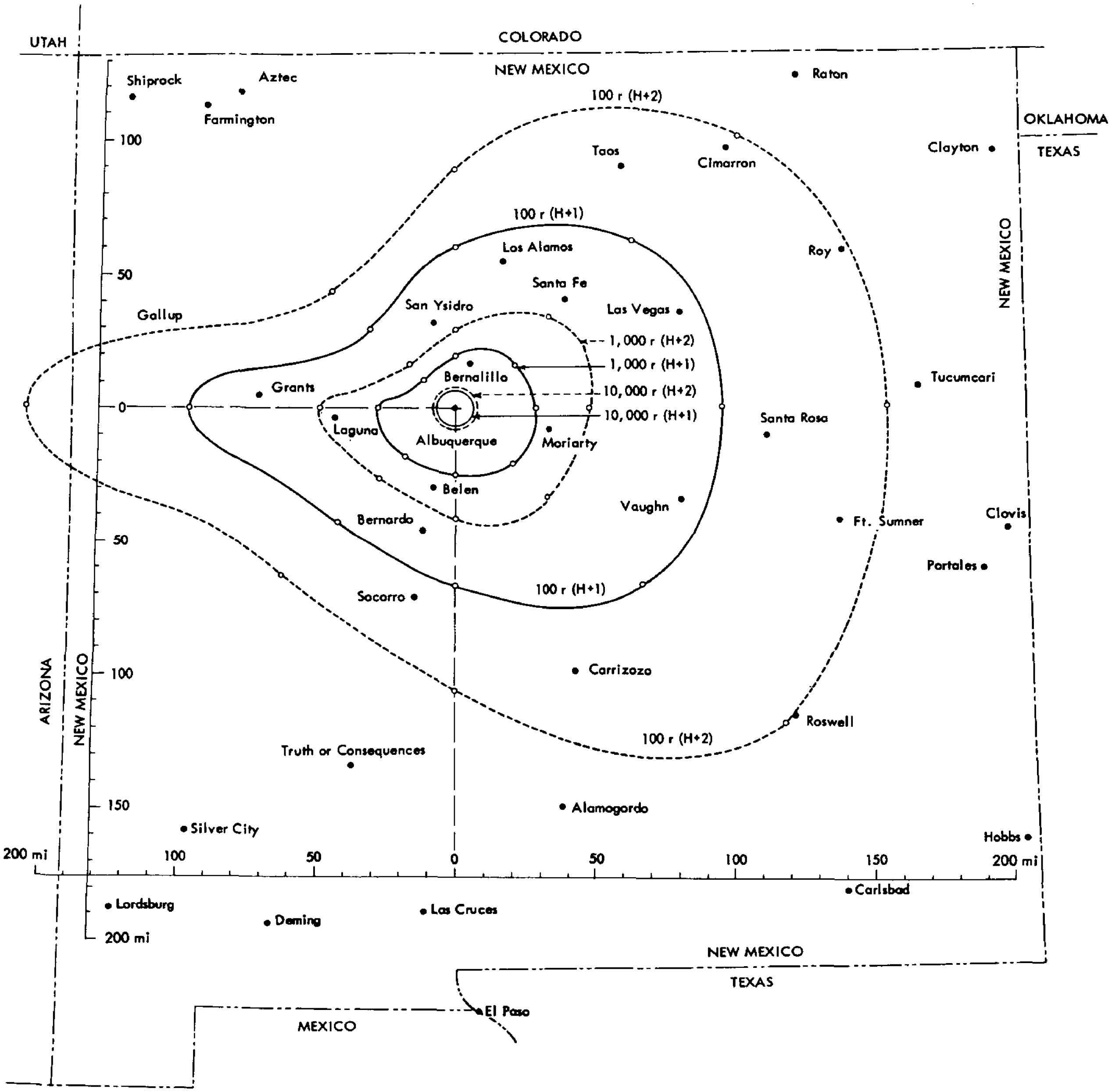


FIGURE 28: COMPUTED "MAXIMIZED" INFINITY ISODOSE CONTOURS FOR 20-MT BURST

"Maximized" infinity isodose contours from penetrating fallout radiation were computed at the nearer ranges for a 1-Mt ($^2/_3$ fission yield) and a 20-Mt ($^1/_2$ fission yield) surface burst at Albuquerque using wind data over five years for the spring seasons, showing contours for exposure doses accumulated over infinite time of 5000, 10,000, and 30,000 r for the 20-Mt burst and of 1000, 3000, and 6000 r for the 1-Mt burst. The contours set forth the maximal ranges over a five-year period inside which the accumulated infinity dose was the stated amount or more. The reader is again cautioned not to confuse the contours with those applicable to the wind pattern of a specified date. Computations and data were supplied by Sandia Corporation, Albuquerque, N. Mex.

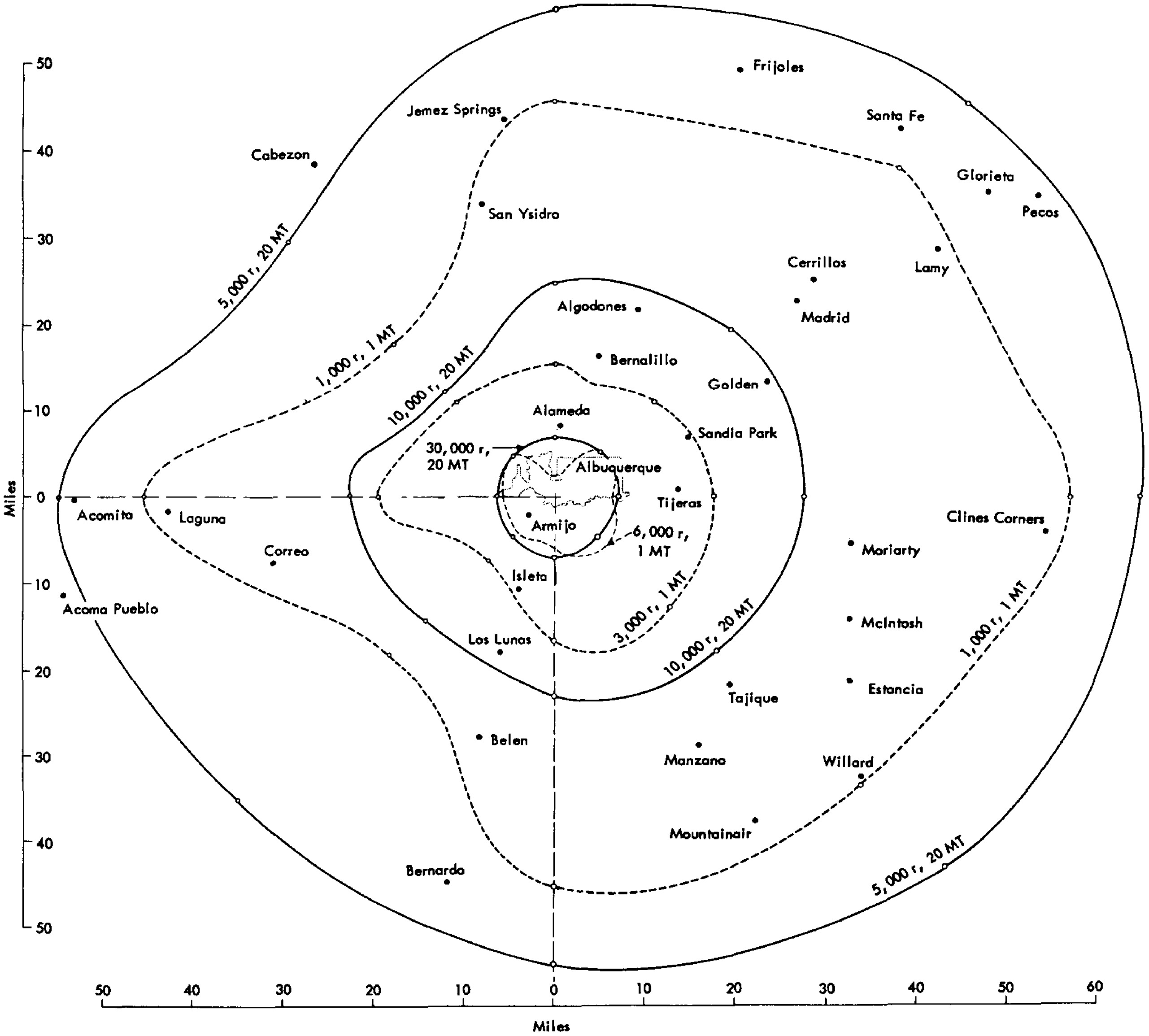
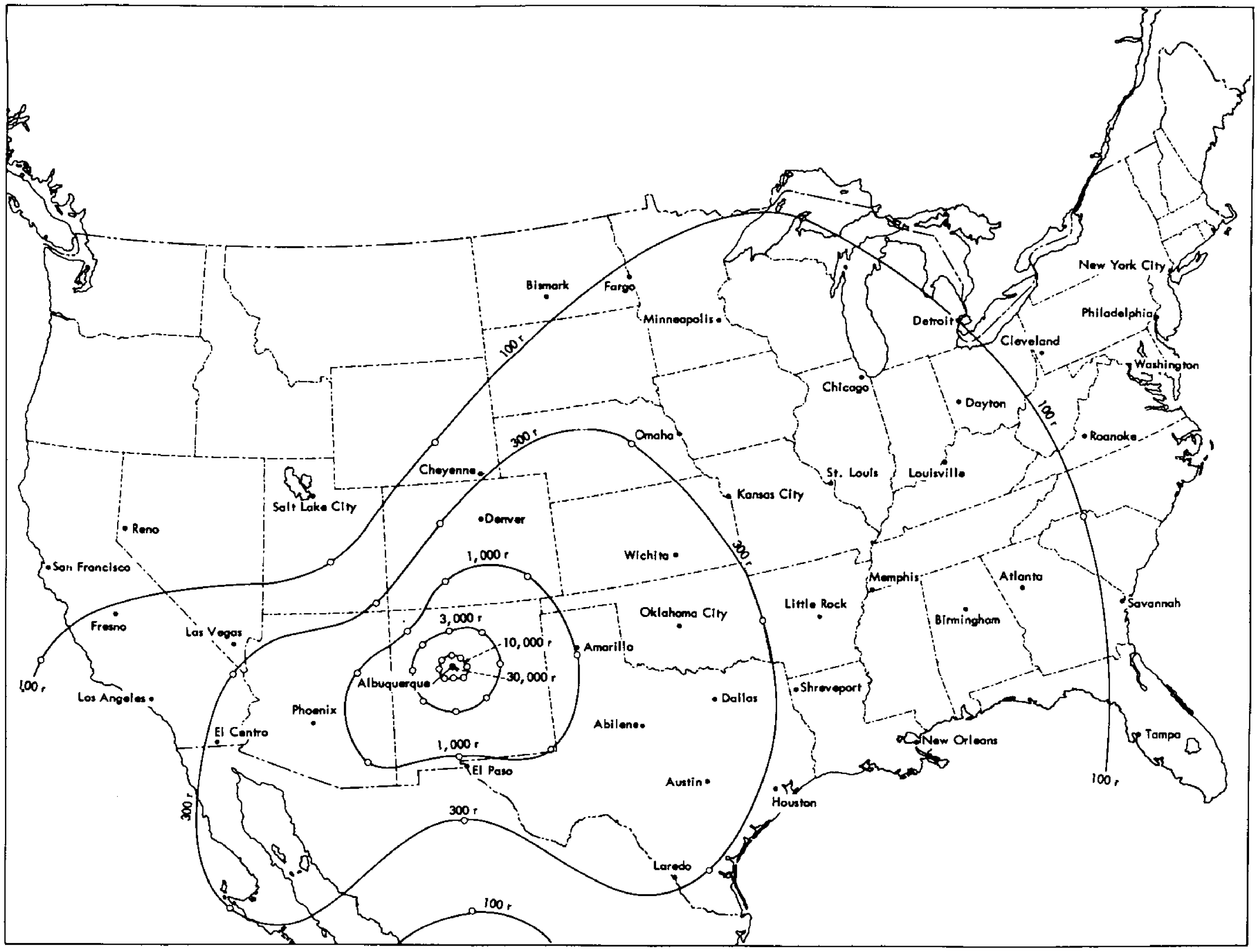


FIGURE 29: COMPUTED "MAXIMIZED" INFINITY ISODOSE CONTOURS FOR 20-MT BURST

"Maximized" infinity isodose contours from penetrating fallout radiation were computed at the near and farther ranges for a 20-Mt surface burst (10 Mt fission yield) at Albuquerque using wind data over five years (all seasons), showing contours for infinity exposure doses of 100, 300, 1000, 3000, 10,000, and 30,000 r. The contours set forth the maximal range and direction that might occur for the stated infinity dose over a five-year period. Thus, one can say that at least once in five years (1825 days) the indicated infinity doses were predicted to reach the ranges shown. The probability of the maximal ranges shown occurring are quite remote, being numerically $^1/_{1825} = 0.00055$. Too, there is some uncertainty concerning the stability, range, and duration of the high winds at the greater altitudes. Even so, the figure serves to emphasize, first, that some wind patterns are such as to carry fission debris over very great ranges, and, second, that planning protection and measures for minimizing exposure to fallout radiation applicable to any one area cannot be realistically approached without thinking of potential targets in nearby states. Data and computations were supplied by Sandia Corporation, Albuquerque, N. Mex.



BIBLIOGRAPHY

1. Auxier, J. A., Evaluation of Residential Structures for Shielding Against Fallout Radiation, pp. 148-151, *Biological and Environmental Effects of Nuclear War,* Hearings Before the Special Committee on Radiation of the Joint Committee on Atomic Energy, June 22-26, 1959, U. S. Government Printing Office, Washington 25, D. C., 1959.
2. Auxier, J. A., J. O. Buchanan, C. Eisenhauer, and H. E. Menker, Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, Civil Effects Test Operations, USAEC Report CEX-58.1, Jan. 19, 1959.
3. Benzinger, T., Physiological Effects of Blast in Air and Water, Chap. XIV-B, *German Aviation Medicine, World War II,* Vol. II, pp. 1225-1259, U. S. Government Printing Office, Washington 25, D. C., 1950.
4. Blizard, E. P. and J. M. Miller, Radiation Attenuation Characteristics of Structural Concrete, Report ORNL-2193, Oak Ridge National Laboratory, Aug. 29, 1958.
5. Bowen, I. G., A. F. Strehler, and M. B. Wetherbe, Distribution and Density of Missiles from Nuclear Explosions, Operation Teapot Report, WT-1168, Dec. 14, 1956.
6. Bowen, I. G., D. R. Richmond, M. B. Wetherbe, and C. S. White, Biological Effects of Blast from Bombs. Glass Fragments as Penetrating Missiles and Some of the Biological Implications of Glass Fragmented by Atomic Explosions, USAEC Report AECU-3350, Lovelace Foundation for Medical Education and Research, June 18, 1956.
7. Brooks, J. W., F. H. Schmidt, R. C. Williams, and W. T. Ham, Jr., Effect of Skin Pigmentation on Flash Burns in Human Volunteers, *Surgical Forum,* 8: 125-128, (1958).
8. Butterfield, W. J. H., E. R. Drake Seager, J. R. B. Dixey, and E. E. E. Treadwell, Flash Burns from Atomic Weapons. 1. Observations on Flash-burning of Human Subjects in the Laboratory Using Infrared and Predominantly White Light Sources, *Surg. Gynecol. Obstet.,* 103: 655-665 (1956).
9. Byrnes, V. A., Flash Blindness and Chorioretinal Burns Produced by Atomic Flash, *J. Am. Med. Assoc.,* 168: 778-779 (1958).
10. Callan, E. J., Concrete for Radiation Shielding, *J. Am. Concrete Inst.,* 25(11): 17-44 (1953).
11. Celander, Hjördis, Carl-Johan Clemendson, Ulf A. Ericsson, and Holter I:son Hultman, A Study on the Relation Between the Duration of a Shock Wave and the Severity of the Blast Injury Produced by It, *Acta Physiol. Scand.,* 33: 14-18 (1955).
12. Clemedson, Carl-Johan, An Experimental Study on Air Blast Injuries, *Acta Physiol. Scand.,* 18, *Supplement* 61: 1-200 (1949).
13. Cowan, Maynard, Jr., A Slide Rule Fallout Calculator, Technical Memo SCTM 177-57(51), Sandia Corporation, Sandia Base, Albuquerque, N. Mex., Oct. 1, 1956.
14. De Haven, Hugh, Mechanical Analysis of Survival in Falls from Heights of 50 to 150 Feet, *War Med.,* 2: 586-596 (1942).
15. De Haven, Hugh, Mechanics of Injury Under Force Conditions, *Mech. Eng.,* 66: 264-268 (1944).
16. Desaga, Hans, Blast Injuries, Chap. XIV-D, *German Aviation Medicine, World War II,* Vol. II, pp. 1274-1293, U. S. Government Printing Office, Washington 25, D. C., 1950.
17. Draeger, R. H., J. S. Barr, J. Y. Dunbar, W. W. Sager, and M. C. Shelesnyak, A Study of Personnel Injury by "Solid Blast" and the Design and Evaluation of Protective Devices, Naval Medical Research Institute Report No. 1, Project X-517, Bethesda, Md., Mar. 30, 1945.

18. Eisenhauer, C. M., Shielding from Fallout Radiation, pp. 151-163 of *Biological and Environmental Effects of Nuclear War*, Hearings Before the Special Committee on Radiation of the Joint Committee on Atomic Energy, June 22-26, 1959, U. S. Government Printing Office, Washington 25, D. C., 1959.
19. Evans, E. I., J. W. Brooks, F. H. Schmidt, R. C. Williams, and W. T. Ham, Jr., Flash Burn Studies on Human Volunteers, *Surgery*, 37: 280-297 (1955).
20. Fisher, R. B., P. L. Krohn, and S. Zuckerman, The Relationship Between Body Size and the Lethal Effects of Blast, Ministry of Home Security Report B.P.C. 146/W.S.11, Nov. 23, 1941.
21. Fisher, R. B., P. L. Krohn, and S. Zuckerman, The Relationship Between Body Size and the Lethal Effects of Blast, Ministry of Home Security Report R.D. 284, Dec. 10, 1941.
22. Gerstner, H. B., Military and Civil Defense Aspects of the Acute Radiation Syndrome in Man, Report AF-SAM-58-6, Air Force School of Aviation Medicine, Randolph Air Force Base, Texas, July 1957.
23. Gerstner, H. B., Acute Clinical Effects of Penetrating Nuclear Radiation, *J. Am. Med. Assoc.*, 168: 381-388 (1958).
24. Glasstone, Samuel, Ed., *Effects of Nuclear Weapons*, U. S. Government Printing Office, Washington 25, D. C., June 1957.
25. Gurdjian, E. S., J. E. Webster, and H. L. Lissner, Studies on Skull Fracture with Particular Reference to Engineering Factors, *Am. J. Surgery*, 78: 736-742 (1949).
26. Ham, W. T., Jr., H. Wiesinger, F. H. Schmidt, R. C. Williams, R. S. Ruffin, M. C. Shaffer, and D. Guerry III, Flash Burns in the Rabbit Retina as a Means of Evaluating the Retinal Hazard from Nuclear Weapons, *Am. J. Ophthalmol.*, 46: 700-723 (1958).
27. Journée, Relationship Between the Kinetic Energy of Bullets and the Seriousness of Wounds Which They May Inflict, *Rev. D'Artillerie*, May 1907.
28. Kinsman, Simon, Ed., Fredric D. Anderson, Richard S. Cleveland, Bennett L. Harless, and Charles F. Henke, *Radiological Health Handbook*, Public Health Service, U. S. Department of Health, Education and Welfare, Office of Technical Services, U. S. Department of Commerce, Washington, D. C., January 1957.
29. Price, B. T., C. C. Horton, and K. T. Spinney, *Radiation Shielding*, Pergamon Press, London, 1957.
30. Richmond, D. R., R. V. Taborelli, I. G. Bowen, T. L. Chiffelle, F. G. Hirsch, B. B. Longwell, J. G. Riley, C. S. White, F. Sherping, V. C. Goldizen, J. D. Ward, M. B. Wetherbe, V. R. Clare, M. L. Kuhn, and R. T. Sanchez, Blast Biology—A Study of the Primary and Tertiary Effects of Blast in Open Underground Protective Shelters, Operation Plumbbob Report, WT-1467, June 30, 1959.
31. Richmond, D. R., R. V. Taborelli, F. Sherping, M. B. Wetherbe, R. T. Sanchez, V. C. Goldizen, and C. S. White, Shock Tube Studies of the Effects of Sharp-rising, Long-duration Overpressures on Biological Systems, USAEC Report TID-6056, March 1959.
32. Richmond, D. R., M. B. Wetherbe, R. V. Taborelli, T. L. Chiffelle, and C. S. White, The Biologic Response to Overpressure. I. Effects on Dogs of Five to Ten-second Duration Overpressures Having Various Times of Pressure Rise, *J. Aviat. M.*, 28: 447-460 (1957).
33. Ritchie, R. H. and G. S. Hurst, Penetration of Weapons Radiation: Application to the Hiroshima-Nagasaki Studies, *Health Physics*, 1: 390-404 (1959).
34. Ruff, Siegfried, Brief Acceleration: Less than One Second, Chap. VI-C, *German Aviation Medicine, World War II*, Vol. I, pp. 584-597, U. S. Government Printing Office, Washington 25, D. C., 1950.
35. Schardin, H., The Physical Principles of the Effects of a Detonation, Chap. XIV-A, *German Aviation Medicine, World War II*, Vol. II, pp. 1207-1244, U. S. Government Printing Office, Washington 25, D. C., 1950.
36. Schwartz, M. S., H. S. Soroff, E. Reiss, and P. A. Curtis, An Evaluation of the Mortality and the Relative Severity of Second- and Third-degree Injuries in Burns, Research Report MEDEW-RS-12-56, U. S. Army Medical Research Unit, Brooke Army Medical Center, Fort Sam Houston, Texas, December 1956.
37. Smith, Byron and William F. Regan, Jr., Blow-out Fracture of the Orbit, *Am. J. Ophthalmol.*, 44: 733-739 (1957).

38. Stewart, George M., The Resistance of Rabbit Eye to Steel Spheres and Cubes, Technical Report CWLR-2332, U. S. Army Chemical Warfare Laboratories, Army Chemical Center, Md., January 1960.
39. Strickler, T. D. and J. A. Auxier, Experimental Evaluation of Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, Civil Effects Test Operations, USAEC Report CEX-59.13, Apr. 14, 1960.
40. Taborelli, R. V., I. G. Bowen, and E. R. Fletcher, Tertiary Effects of Blast—Displacement, Operation Plumbbob Report, WT-1469, May 22, 1959.
41. Vortman, L. J., Curves for Estimating Low Blast Overpressures, Technical Memo SCTM 195-58(51), Sandia Corporation, Sandia Base, Albuquerque, N. Mex., Apr. 15, 1958.
42. White, C. S. and D. R. Richmond, Blast Biology, USAEC Report TID-5763, September 1959; also to appear (in part) as Chap. 63 of *Clinical Cardiopulmonary Physiology,* Grune & Stratton, Chicago, Ill. (in press).
43. White, C. S., T. L. Chiffelle, D. R. Richmond, W. H. Lockyear, I. G. Bowen, V. C. Goldizen, H. W. Merideth, D. E. Kilgore, B. B. Longwell, J. T. Parker, F. Sherping, and M. E. Cribb, Biological Effects of Pressure Phenomena Occurring Inside Protective Shelters Following a Nuclear Detonation, Operation Teapot Report, WT-1179, October 1957.
44. White, C. S., Biological Blast Effects, USAEC Report TID-5564, Lovelace Foundation for Medical Education and Research, September 1959.
45. Young, D. A. and W. W. Bledsoe, Program for Rapidly Computing Fallout from a Thermonuclear Burst using a Shear Fallout Model, Technical Memo SCTM 194-59(51), Sandia Corporation, Sandia Base, Albuquerque, N. Mex. (in preparation).
46. Young, D. A., Fallout Contours at Albuquerque, New Mexico, Technical Memo SCTM 195-59(51), Sandia Corporation, Sandia Base, Albuquerque, N. Mex., January 1960.
47. Zalewski, T., Experimentelle Untersuchungen über die Resistenzfähigkeit des Trommelfells, *Z. Ohrenheilkund,* 52: 109-128 (1906).
48. Report of the International Commission on Radiological Units and Measurements (ICRU), Handbook 62, National Bureau of Standards, U. S. Department of Commerce, U. S. Government Printing Office, Washington 25, D. C., Apr. 10, 1957.
49. *Exposure to Radiation in an Emergency,* National Council on Radiation Protection, Subcommittee 14 Handbook, in draft.
50. *The Biological Effects of Atomic Radiation,* Summary Report from a study by the National Academy of Sciences, NAS-NRC, Washington, D. C., 1956.
51. *The Adequacy of Government Research Programs in Non-Military Defense,* National Academy of Sciences–National Research Council Report, Washington, D. C., 1958.
52. Results of the Teak and Orange Shots in the 1958 Hardtack Series, Joint AEC-DOD News Release, Washington, D. C., June 15, 1959.

CIVIL EFFECTS TEST OPERATIONS REPORT SERIES (CEX)

Through its Division of Biology and Medicine and Civil Effects Test Operations Office, the Atomic Energy Commission conducts certain technical tests, exercises, surveys, and research directed primarily toward practical applications of nuclear effects information and toward encouraging better technical, professional, and public understanding and utilization of the vast body of facts useful in the design of countermeasures against weapons effects. The activities carried out in these studies do not require nuclear detonations.

A complete listing of all the studies now underway is impossible in the space available here. However, the following is a list of all reports available from studies that have been completed. All reports listed are available from the Office of Technical Services, Department of Commerce, Washington 25, D. C., at the prices indicated.

CEX-57.1 ($0.75)	The Radiological Assessment and Recovery of Contaminated Areas, Carl F. Miller, September 1960.
CEX-58.1 ($2.75)	Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, J. A. Auxier, J. O. Buchanan, C. Eisenhauer, and H. E. Menker, January 1959.
CEX-58.2 ($0.75)	The Scattering of Thermal Radiation into Open Underground Shelters, T. P. Davis, N. D. Miller, T. S. Ely, J. A. Basso, and H. E. Pearse, October 1959.
CEX-58.7 ($0.50)	AEC Group Shelter, AEC Facilities Division, Holmes & Narver, Inc., June 1960.
CEX-59.1 ($0.60)	An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building, J. F. Batter, Jr., A. L. Kaplan, and E. T. Clarke, January 1960.
CEX-59.13 ($0.50)	Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, T. D. Strickler and J. A. Auxier, April 1960.